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Technical and Economic Analysis of US Offshore Wind Power

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Technical and Economic Analysis of US Offshore Wind Power

By

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Thesis

Presented to the Faculty of the Graduate School

of the University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Arts

The University of Texas at Austin

May 2011

This work is

dedicated to my husband,

William,

and our daughter.

Acknowledgements

I thank my advisor Dr. Jablonowski for his guidance and assistance, particularly for his help assessing the model, my committee members, Dr. Webber and Dr. Manuel, and my supervisor, Dr. Malik. I also would like to thank the Texas General Land Office for sharing information about their offshore wind leases. Last, I give special thanks to Baryonyx Corporation for their time and assistance assessing the capital cost model.

Technical and Economic Analysis of US Offshore Wind Power

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Constance Annette McDaniel Wyman, MA

The University of Texas at Austin, 2011

SUPERVISOR: Christopher Jablonowski

Wind power is the fastest growing sector of electricity generation in the world and the development of offshore wind resources is an increasingly important component of this growth. While more than 1.5GW have been installed in Europe and China, no turbines have been installed in United States waters even though several have been planned.

Offshore wind power development in the United States must contend with significant challenges. There are numerous technical considerations including geological issues and undefined environmental conditions that affect the determination of appropriate design loads. Technological advancements are needed, and logistical questions must be addressed. The regulatory structure can be confusing and most permitting frameworks are not well established. Offshore wind projects are capital intensive and concerns exist that the industry will not be able to achieve a suitable economy of scale. Additionally, concerns about offshore wind impacts cross many areas such as the environment, visual and cultural concerns, navigational issues, and competing uses.

This research project examines the technical issues of American offshore wind power and models basic project costs to provide an estimate of the total net present value for hypothetical utility-scale offshore wind projects in the United States. Costs have been examined by building a cost model and employing traditional cash flow analysis, regression, design of experiments, and random sampling techniques.

Table of Contents

List of Tables

List of Figures

Chapter One: Introductory Remarks

Over the last twenty years offshore wind power generation has been gaining momentum and attracting increasing amounts of attention – for good reason. Forty-four percent of the world's population now lives within 150 miles of coasts and urban, coastal population growth continues to increase[72]. This growing population increases demand for energy and puts pressure on existing power generation sources. Offshore wind power generation provides a local energy source with minimal pollution. It also is a low carbon source of electricity, which has become increasingly popular with the considerations brought by climate change and the resulting focus on carbon emission reduction.

Offshore wind power has numerous pluses. Offshore winds tend to be stronger, more consistent, and less turbulent than their onshore counterpart, which translates in to a more dependable source of electricity[80]. In addition to being in proximity to large potential customer bases, offshore wind power can take advantage of larger wind turbine size than onshore sites, in part because there is little need to consider noise pollution from turbines[20], which helps the cost analysis.

Wind power is the fastest growing sector of electricity generation in the world with installed capacity increasing from 2,500 MW in 1992[60] to 120,800 MW at the end of 2008[9]. The development of offshore wind resources has become a key component of this growth. Offshore wind power projects have grown exponentially since the first project was built in shallow European waters in 1991[80]. From 2000 to 2009 offshore wind power generation increased from nearly non-existent to 1,900 MW of installed power[50]. Of the wind generating capacity in operation worldwide in 2008, about 1,471 MW of those were offshore, all in Europe[9]. Figures 1.1 and 1.2 show wind energy growth in total wind and offshore wind, respectively.

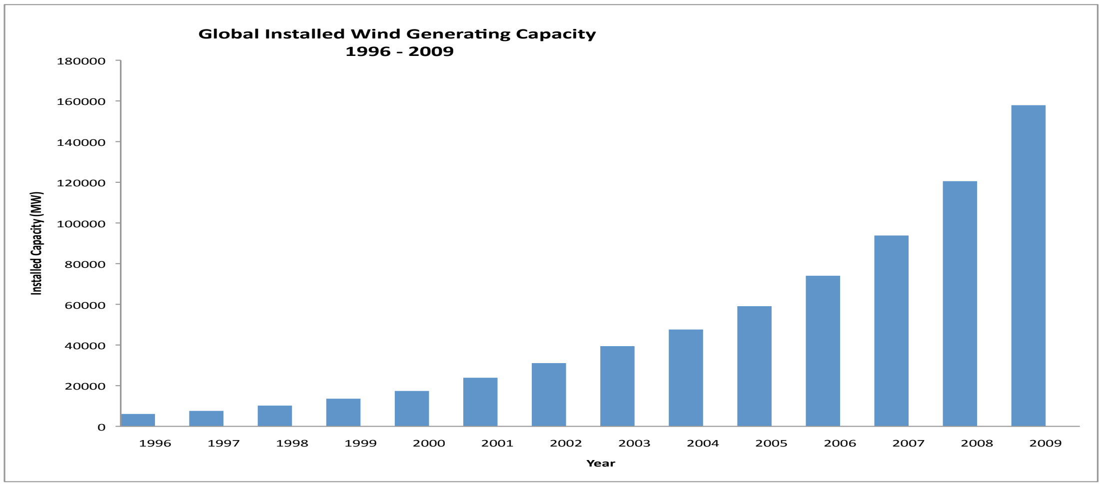


Figure 1.1: Global Installed Wind Generating Capacity[39]

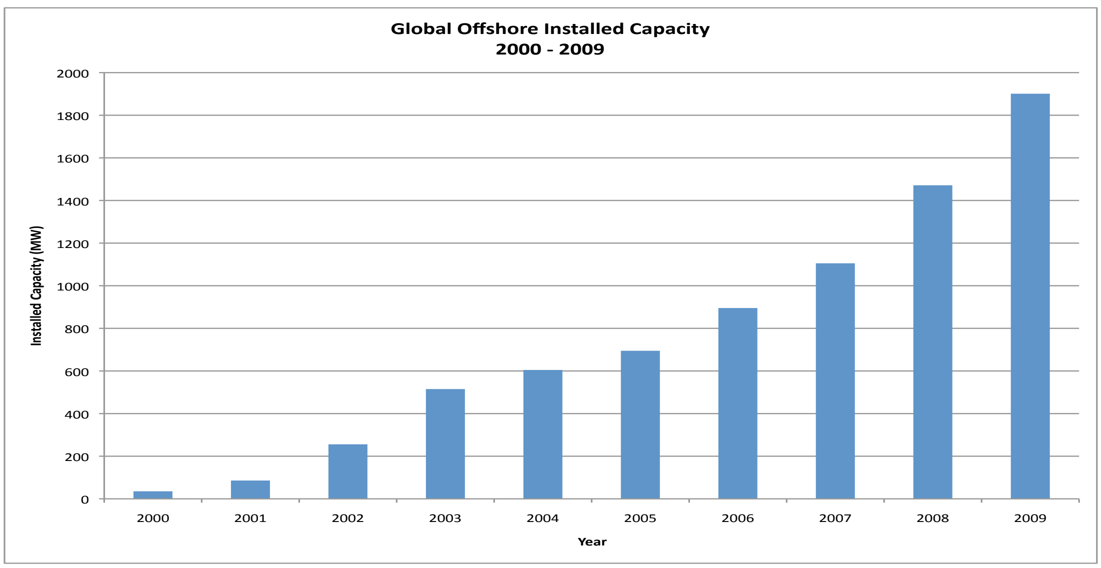


Figure 1.2: Global Offshore Installed Capacity[33]

This decade should be very exciting for the offshore wind energy industry. At the end of 2010 there were forty-seven projects installed in nine countries in Europe and two in Asia, including demonstration projects[35], with more under development on both continents. Appendix One list the projects by location, capacity and age. The majority of early offshore projects were installed in Denmark, but the United Kingdom now has more installed capacity and Germany has begun construction of the more than 8,500 MW it has approved[35]. New projects are planned across Europe and in China, and the United States is exploring its offshore wind possibilities. Projections suggest that worldwide more than 5,000 MW will be installed by 2012[50] – an increase of 3,500 MW over 2009 numbers, or more than double.

In the United States current installed wind capacity is over 35,000MW and wind electricity generation provided 1.8% of the nation's electricity in 2009[10]. In the same year new wind projects provided 39% of all new American electric generating capacity[10]. Despite the rapid growth in the domestic wind industry as a whole, offshore wind power in the United States is a fledgling industry. Even worldwide it still is quite young. The United States has offshore areas that generally have high enough wind speeds to support offshore wind development, but progress toward the installation of these projects has been slow. However, the industry is building momentum and numerous parties are working to resolve the existing issues.

Although the United States has no installed offshore wind projects several have been proposed and are in various stages of the development process[90]. A few of the projects are in near-shore waters that fall under federal jurisdiction, and one, the Cape Wind project in Massachusetts, has received final federal approval from the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)[18]. Many of the proposed projects are in state waters and several have obtained leases in Texas. Four Great Lakes states and several Atlantic states have expressed interest in the installation of offshore projects in their state waters.

Despite the advantages provided by nearby, clean, domestic energy several challenges exist for an American offshore wind industry. The total costs for the development of offshore wind power generation are higher than for comparable onshore installations. This higher cost is the result of increases in site surveys, pre-project assessments and planning, additional installation/construction costs, and higher operational and maintenance expenses. Add in access challenges, weather delays, possible technical problems, and permitting requirements that still are being crafted and one can see that there also is a large amount of uncertainty and risk as well.

In order for offshore wind projects to be economical they generally must be large scale, which requires a considerable expenditure of capital[80]. High capital costs and expensive operation and maintenance costs equal sensitivity to the amount of equity available and the cost of capital. Pair this sensitivity and cost with the youth of the industry and degree of uncertainty, and the result is that there is no set formula for financing of offshore wind power projects. Each of the existing projects has a unique monetary structure and many factors vary depending on the incentives available.

This paper summarizes the current status of this developing industry and examines the viability of offshore wind power generation in the United States. It concludes with a theoretical approach to modeling domestic project costs. The chapters are organized as follows.

The second chapter looks at the technical considerations of offshore wind power projects and also examines some of the logistics. Working in a marine environment carries with it complexities that do not have comparable counterparts in the onshore industry. The nature of the environment means that systems must be hardier, more reliable, and resistant to corrosion. Many factors must be considered in the early stages of planning an offshore wind project from geology and wind resource to available components to modeling of expected design loads.

The viability of offshore wind projects in the United States is affected by legislation and regulatory requirements at both the state and federal levels. Chapter three offers a synopsis of regulatory issues affecting the industry. It also discusses the intricacies of obtaining state and federal leases and permits.

Various aspects of offshore wind projects have the potential for different impacts. Chapter four briefly will discuss these impacts. Construction and decommissioning, maintenance, and regular operation phases each have unique factors that must be considered.

Everything discussed to this point impacts the costs associated with offshore wind power development. The capital costs required to develop an offshore wind power generation project act as a significant barrier to entry into the industry. Capital costs for offshore projects are higher than those for onshore projects although they represent a lower percentage of the total project costs for the life of the project[17]. Chapter five discusses the challenges to and available options for financing offshore wind projects.

Chapter six will present a theoretical model of the costs required to develop and construct an offshore wind power project in the United States and examine project cash flows. Explanation of the modeling approach and methods, assumptions, and data sources and a discussion of the results are included.

The last chapter presents the conclusions.

Many challenges exist in developing a vibrant offshore wind power industry in the United States and many lessons can be learned from experience in Europe and from the domestic oil and gas industries. The potential gains to the US from this untapped natural, renewable resource is well worth the effort.

Chapter Two: General Offshore Wind Considerations

The offshore wind industry is a merger between traditional wind turbine design that originated with land-based operations, and offshore structural design. In general, initial installed offshore wind projects took on-shore turbine designs and placed them on offshore foundations, although a clear trend toward the development of marine specific turbines has emerged.

Working in a marine environment carries with it complexities that do not have comparable counterparts in the onshore industry which means that turbines must be marine-ized. The nature of the offshore environment means that systems must be hardier, more reliable, and resistant to corrosion. Also, logistical issues and access requirements affect the initial installation as well as the ongoing maintenance and operation of the facilities.

Many factors affect the developing offshore wind industry and create challenges that must be addressed. Areas suitable for projects must be identified and preliminary data collected to verify the conditions at the site and identify parameters that affect structural and mechanical loads and thus project design. Such factors include meteorological, oceanographic, and geologic characteristics, quantification of available wind resource, determination of necessary foundation characteristics, location water depth and distance to shore, geotechnical analysis, and seafloor topography. Aside from these routine factors structural loads resulting from extreme environmental conditions resulting from tropical systems, northeastern storms, and ice, as well as the accumulation of marine growth must be considered.

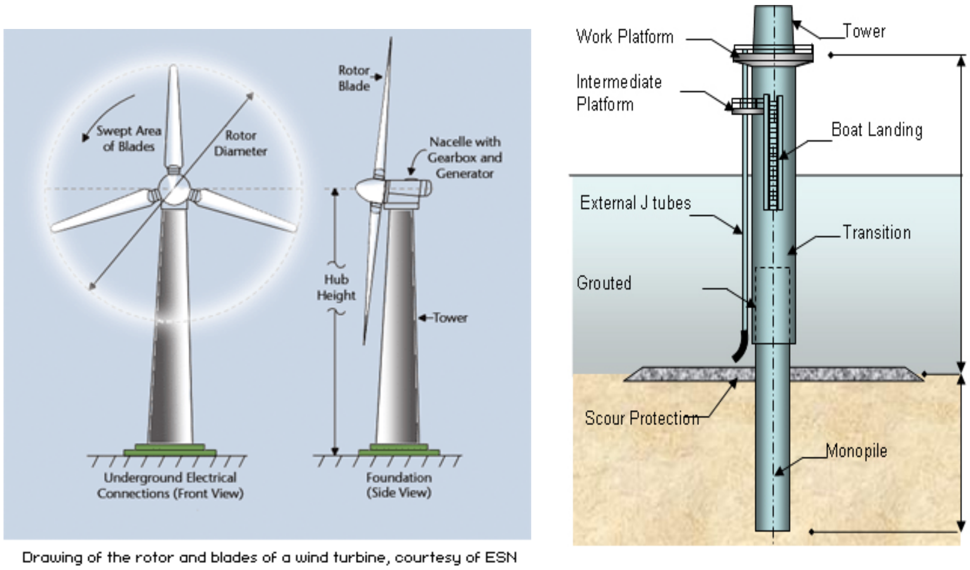
Other technological and logistical challenges exist. Advancements are needed in turbine technology, reliability enhancements including remote monitoring and forecasting, and creation of design standards. Different approaches for project installation must be assessed including the availability of necessary vessels and a domestic supply chain must be established. Last, transmission elements must be considered including the layout and routing of collection and transmission lines and availability of shore connection.

2.1 Offshore Wind Basic Project Arrangement

Offshore wind farms consist of an array of turbines arranged either in a line or a grid with spacing adequate to minimize turbine-turbine interaction (i.e. wake effects). Installed utility-electricity scale offshore wind projects use horizontal axis, lift type turbines. Each turbine consists of a foundation, transition piece, tower, yaw mechanism, nacelle, and rotor - including blades.

Foundations support the structures and resist the overturning forces created by the wind loading over the rotor swept area. The transitional piece basically is a large flange that connects the foundation and support structure to the turbine tower and holds J-tubes to allow connection of the electricity collection cable. It usually also provides an access ladder for maintenance. The tower supports the turbine and elevates it to the appropriate height, as shown in Figure 2.1. It allows access to the turbine components and protects electrical equipment from the marine environment.

The yaw mechanism, nacelle, and rotor sit atop the tower. The yaw mechanism allows the top of the turbine to be rotated into (or out of) the direction of the wind because the wind direction and blade frontal area must be perpendicular during normal operation[98]. The nacelle contains the generator, electrical switches, gearbox and clutch, bearings, and the rotor shaft and brake. The rotor consists of the shaft, a hub (which may contain pitch control mechanisms), and blades. A general diagram of turbine nacelle components can be seen in Figure 2.2. Basically the blades of the rotor turn in response to the aerodynamic force applied by the wind which rotates the shaft and the gears that are connected to the generator, generating electricity.



(a) Turbine Configuration[104] (b) Support Structure Configuration[65]

Figure 2.1: Offshore Wind Turbine Arrangement

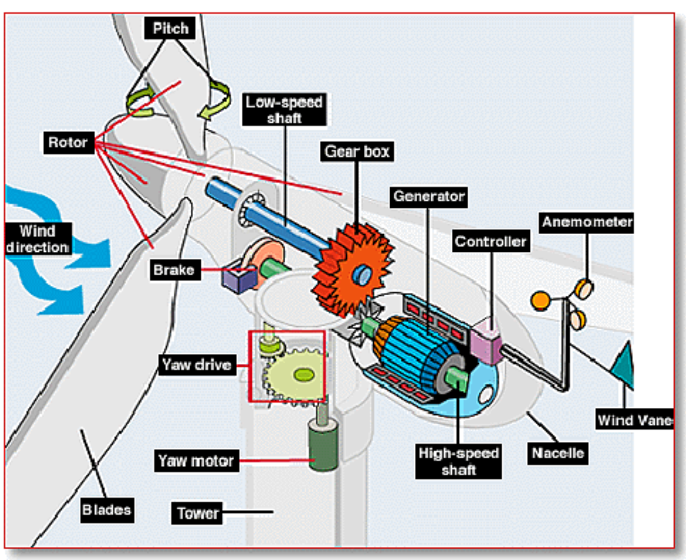


Figure 2.2: Nacelle Inset[105]

Once generated, electricity passes through internal electrical equipment such as rectifiers, inverters and direct current links, or soft-start and power factor correctors, depending on configuration[98]. At the base of the tower it passes through a transformer where it is transferred to an internal grid connection cable at medium voltage. Connection cables are attached to an offshore substation where the voltage is stepped-up to a higher voltage for transmission to shore[40].

High voltage, smaller diameter cables transmit the power to shore and, after making landfall, connect to an onshore substation, as shown in Figure 2.3. Depending on the capacity of the project or desire for redundancy multiple transmission cables and onshore substations may be used. This also is true of offshore substation(s)[40]. From this point additional equipment may be used to match the electricity to grid requirements and then the electricity is transmitted into the power grid.

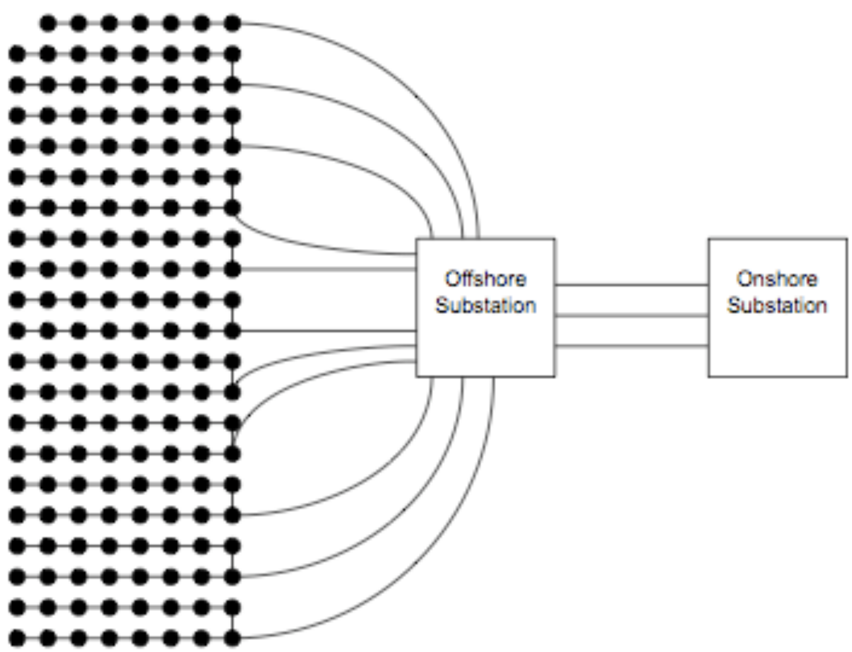


Figure 2.3: 500 MW Wind Farm Layout with 3MW turbines (not to scale)[40]

2.2 Geological Issues and Determination of Design Loads

Geologic considerations must be factored into design requirements for wind turbines, the plans for offshore installation, and for the transmission/distribution facilities. For this reason it is necessary in the early stages of the development of offshore projects to study the geology and geotechnical characteristics, expected wind resource, and oceanographic conditions at the proposed site.

Pre-project surveys must be performed to ensure that the proposed project area is suitable for wind power development. First, an assessment of the wind resource and bathymetry in the planned location must be conducted. Second, bottom surveys must be conducted to identify the locations of any existing infrastructure or pipelines and topographic features that pass through the area. The locations of existing assets in the project area are critical in determining site layout including planning the route for the required subsea cable installation and its protection, tie-in with other offshore structures, shoreline approach and cable crossings. Third, geotechnical analysis must be completed to identify the type of substrate and its characteristics.

In addition to assessing the conditions in the project area, offshore wind projects must consider forces resulting from extreme environmental conditions. For United States waters this includes hurricanes, northeastern storms, and ice loading.

2.2.1 Available Resource

The available wind resource, predominant direction, and mean wind profile/shear affect the type, size, and design of turbine as well as the configuration that will be selected for a specific project. Offshore wind power is more reliable and continuous than wind power from onshore locations. The Offshore Wind Feasibility in the Great

Lakes report found that, "Preliminary data from the few available offshore wind monitoring stations in the Great Lakes indicate both higher average wind power density and steadier winds offshore[58]." Offshore winds also tend to be continuous throughout the day which means they match better with electricity demand and could be depended upon to provide fairly steady power generation during peak demand portions of the day.

The United States offshore wind resource is huge, owing to the length of the coastlines and quality of the resource, shown in Figure 2.4 at 90 m altitude. The National Renewable Energy Laboratory (NREL) estimates that the "Offshore wind resource data for the Great Lakes, U.S. coastal waters, and Outer Continental Shelf up to 50 nautical miles from shore indicate that for annual average wind speeds above 8.0 m/s, the total gross resource of the United States is 2,957 GW or approximately three times the generating capacity of the current U.S. electric grid. Of this capacity, 457 GW is in water shallower than 30 m, 549 GW in water between 30 m and 60 m deep, and 1,951 GW in water deeper than 60m[91]."

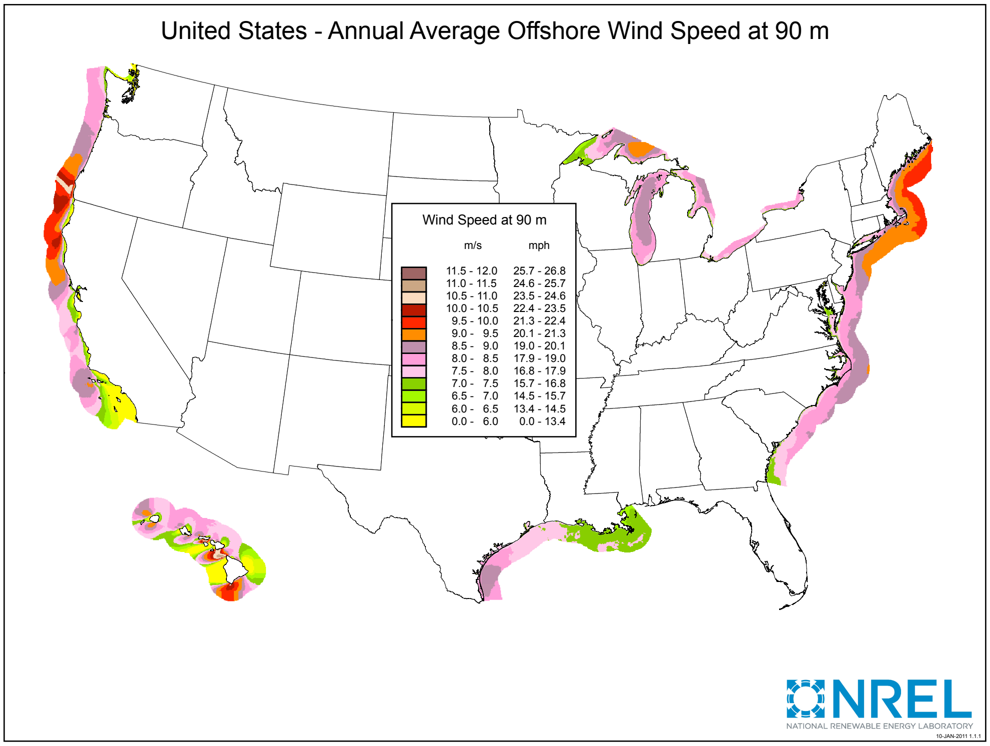


Figure 2.4: United States Offshore Average Mean Wind Speeds at 90m[103]

Thirty states have ocean or lake coastlines and the possibility of wind resources suitable for offshore wind development. In 2010 NREL completed an offshore wind database and published state-by-state resource maps for twenty-six of these states. They produced their estimates using preliminary 1993 resource maps, and data from automated marine stations, Coast Guard lighthouses and stations, satellite-derived microwave images, and ocean buoys. Sufficient data did not exist for Alabama, Florida, and Mississippi, and Alaska was not evaluated[78].

These NREL assessments are a great start to identifying areas suitable for offshore wind farms, but there may be local variations in the wind patterns that have not been captured. After identification of a promising project location meteorological and oceanographic instruments must be deployed to quantify the site-specific resource, and bathymetric and atmospheric profiles.

The amount of power that can be generated varies as the cube of the wind speed:

$$Power = \frac{1}{2}\rho A V^3$$

where power is in Watts, ρ represents air density, A represents frontal area of the blades, and V represents wind speed[98]. Once the resource at the location has been quantified, projections for expected power generation can be calculated based on average wind speeds. Also design parameters can be established to maximize power output and minimize resultant environmental loads.

2.2.2 Geotechnical Considerations

In the early stages of planning an offshore wind project a geotechnical site investigation must be conducted to determine the geology (i.e. bottom type, stratigraphy), presence of geologic hazards (i.e. gas pockets, landslide potential), soil characteristics (i.e. resonant frequency, resistance), and the spatial variance of each at the project site. This analysis typically is performed in stages including geophysical investigation, drilling of boreholes and soil sampling, in-situ electronic testing, and offsite laboratory analysis.

Different methods can be used to simulate and model soil response based on the site characteristics and given turbine design. This modeling process examines plastic and elastic deformation (or movement) of the soil as well as its resistance to deformation. It is crucial in offshore wind projects to design a structure suitable to the local conditions so that the structures will not surpass defined failure limits. This analysis requires the knowledge gleaned during the site investigation process.

The limit state design process usually is used to analyze and predict the reliability of the structure and soil deformation response to offshore wind structures. Limit states are defined in terms of the various parameters that influence design and performance and are used to separate acceptable or safe performance from unacceptable or unsafe performance. The evaluation of four limit states is necessary for analysis of offshore wind projects. Ultimate limit states examine the structural and soil response to maximum loads expected and considers non-degraded soil conditions. Both fatigue and serviceability limit states consider cyclically degraded soil conditions[36] in the evaluation of several load cases. The fatigue state estimates failure expected as a result of cyclic loads during installation and operation. Serviceability limit states look at the soil deformations resulting from structural rotation and settling that may alter operability and are set as criteria acceptable for normal project use.

The last condition is not specifically called a limit state, but considers the soil response to the installation of the structure. During installation failures can result from the force required to overcome the soil strength and resistance when driving piles[77] and total accumulated fatigue damage should be considered[100]. In some areas it may be necessary to use a combination of drilling and driving to install foundations without damage. Typically offshore structures must comply with design criteria issued by industry standardization or regulatory bodies to ensure a minimum level of safety[100].

During the analysis of bottom type it is particularly important to identify the type of substrate and determine its resonant frequency. Resonant frequency is the wave frequency at which a system tends to oscillate with increasing or maximum amplitude. For bottom fixed foundations, it is necessary to ensure that the substrate does not vibrate in the frequency range that includes the vibration frequency of the wind turbine and base, as this condition will exacerbate soil deformation and negatively impact structural stability. This is especially important if planning to install a pile foundation, which may require penetration of the substrate to depths in excess of 100ft[33].

Geotechnical investigation is required both for onshore wind projects and offshore oil and gas installations so the concepts are well understood and can be applied to offshore wind projects. Additional site investigation may be required for offshore wind projects because the loading characteristics are more important while assessing design loads and electricity generation. Another difference from the perspective of the wind industry is that the cost of site investigation offshore can be about two orders of magnitude greater than that for onshore projects[77].

2.2.3 Environmental Loading

Environmental loading results from the forces of the wind, sea state, and currents that act on an offshore structure. All offshore structures are subjected to some combination of these factors and must be able to withstand these forces; however, offshore wind structures are unique from other offshore structures in that wind plays a large role in the determination of loads. In other offshore, or marine applications, wind produces a pushing or lifting force that acts upon the sail area of the vessel or structure[108]. For wind turbines the effect of the local wind regime moving across the rotor blades and the resultant lateral load over the rotor creates an overturning moment that must be considered together with aerodynamic forces acting on the tower, and hydrodynamic forces acting on the submerged support structure.

All of the above factors must be included to determine appropriate design loads for these projects. Calculation of reasonable extreme and fatigue loads depends on realistic modeling of turbine response and the use of suitable input data for wind and wave conditions, much of which is stochastic in nature. Various modeling and simulation techniques can be employed, and ideally, paired with or validated against available field measurement data from the project site.

Exploration of the most suitable methods for this application is ongoing, but while inflow turbulence models used to characterize the wind are well established, the current practice of using linear wave models may not accurately capture the wave interaction in shallow environments where offshore turbines are installed on bottom-fixed foundations. The use of irregular linear wave models may cause the computed loads to appear smaller than if a more realistic non-linear wave model is assumed[5].

Variability in forces and the response of the blades and tower also is affected by factors other than wind regime and sea condition including the cut-in and cut-out thresholds for turbine operation[76] and the action of blade pitch controls[6]. Regardless of which methods are used, it is crucial to consider long term loads possible across the range of wind characteristics expected at the site and over a twenty to fifty year time period[4] since the expected life of offshore wind projects is at least twenty years.

2.2.4 Extreme Environments

Design loads are also affected by the need to survive extreme environmental events. Many lessons can be learned from the domestic oil and gas industry and offshore wind experience in Europe, although there is greater meteorological and oceanographic variability offshore of the United States[48]. This variability is because of different environmental conditions and unique challenges such as hurricanes, northeastern storms, and freshwater ice[81]. These issues must be addressed during the development of American offshore wind power and may require the use of enhanced safety levels for design parameters.

Hurricanes and storms – A major concern of offshore wind development in the United States is the question of how offshore wind farms would be affected by hurricanes and other significant storms, such as northeastern storms. The question of hurricanes is not prominent in Europe where offshore wind development has been centered to date. Occasionally the western coast of Europe is impacted by tropical systems, but by the time these storms reach Europe they usually have decreased in severity considerably compared to the tropical systems that affect the Atlantic and Gulf coasts of the United States.

Both hurricanes and northeastern storms are cyclonic weather systems, but they differ in general characteristics. Hurricanes form in the tropics (though they may become extra-tropical after formation), have warm air at their core, tend to be well defined, and may have diameters reaching about 540 nautical miles. Northeastern storms form at higher latitudes, have colder air at their core, are not as well formed, and have larger diameters than hurricanes[81]. Tropical cyclones can impact the east, west, and Gulf coasts; northeastern storms occur more frequently, but typically impact only the northern Atlantic coast. Measured metocean data for hurricanes at sea is limited which makes modeling of associated wind, wave, and surge uncertain, although mathematical models of hurricane induced conditions exist. Northeastern storms tend to generate less severe winds but their large diameter can allow for a long fetch, resulting in high significant wave heights[81].

This design consideration is critical because operators need to minimize the risk of damage to their structures and loss of operational time. Debate is ongoing about the best approach to take for industry standards, including whether to use 50 or 100-year extreme conditions as will be discussed below. Additional research and development is needed to create better models and to more accurately estimate design conditions associated with hurricanes and storms, as well as to determine how storm specific design features would fare during major storm events.

Ice – Ice and snow and the formation of floating ice are of concern for offshore structures in cold climates. The accumulation of ice and snow on the structures can have severe impacts on stability and loading because weight typically is added well above the center of gravity. Ice can be present as the result of precipitation or form as waves splash against the structures and freeze just above the waterline. Offshore wind structures mitigate ice formation from breaking waves by installing an inverted cone just above the waterline on the transition piece. This issue is well understood as it similarly affects offshore oil and gas facilities.

Of greater concern for United States offshore wind is the formation of floating ice in the Great Lakes. These lakes are freshwater bodies with significant offshore wind potential. Floating ice is more likely to form in fresh water than in salt water, and freshwater ice tends to be stronger than saltwater ice of equal thickness[81]. Since existing offshore wind projects have been installed in saltwater environments, no precedent exists to address this issue although there is some experience with pack ice in the Baltic Sea[70]. Floating freshwater ice will have to be addressed when establishing design parameters for projects in the Great Lakes.

2.2.5 Marine Growth

Marine growth is another environmental factor that must be considered. The accumulation of biological organisms (such as barnacles, mussels, polyps and seaweed) over time at and below the waterline of an offshore structure adds weight that must be included in stability calculations, particularly for floating systems. The presence of these organisms also increases the roughness of the submerged structure which causes an increase in drag and affects the hydrodynamic flow through and around the project.

In general, this issue is well understood for offshore systems and marine growth usually is assumed to accumulate at a given rate that is based upon depth below the waterline, the age of the structure or time elapsed since the last hull cleaning, and the location of the structure. In this area the development of offshore wind should be able to build upon experiences gained in the traditional offshore oil and gas industry.

2.3 Technical Challenges

The issues associated with increased water depth, increased distance from shore, and power grid connection will require improvements in existing technology, development of new technologies, refinement of modeling techniques, and investment in efficiency improvements to yield higher energy capture. Beneficial new technology could lower cost, increase efficiency, increase reliability, and reduce uncertainty within the industry.

New technologies for offshore wind are being developed that would increase the productivity of offshore turbines and could allow the installation of wind turbines in additional areas. Newer offshore wind turbines are larger than older models which means that they will require more robust bases and/or mooring systems, lighter materials such as composites for blades, and gear boxes that can withstand the corrosive nature of the marine environment[9], or a transition to gearless systems.

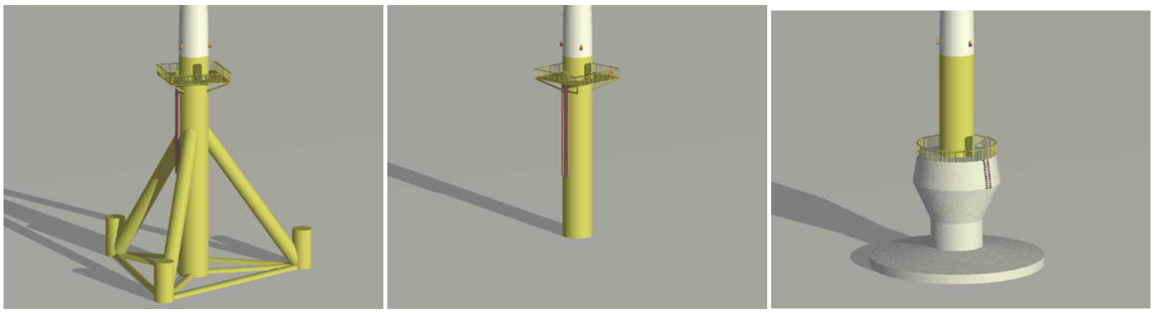
Near term offshore experience in shallow water will accelerate deepwater technology innovation, which is required to capture wind resources further offshore at more reasonable costs[96]. Advancements and creative solutions are needed in areas such as new foundations and moorings, control algorithms and systems, modeling to predict loads generated by extreme environments, and innovation to provide suitable stability to the structures. The Department of Energy is creating The Large Wind Turbine Drive Train Testing facility in Charleston, South Carolina[92], and independent private entities are working to solve these issues as well.

2.3.1 Foundations and Support Structures

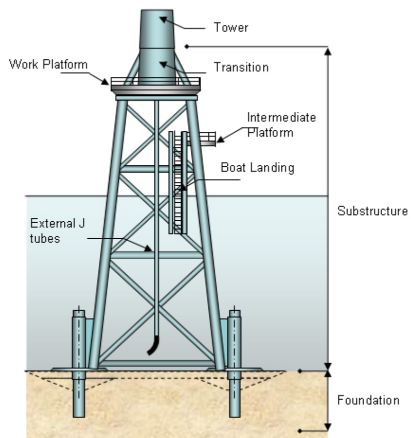
The substructure which supports the turbine represents between 25% and 34% of project capital costs[33]. Variations in parameters that either increase the amount of material required to build a suitable foundation, such as plate thickness or piling depth, or result in additional weight have a direct impact on the economics of a project. Therefore it is important for the viability of a project to pick the most appropriate foundation type and correctly quantify design parameters.

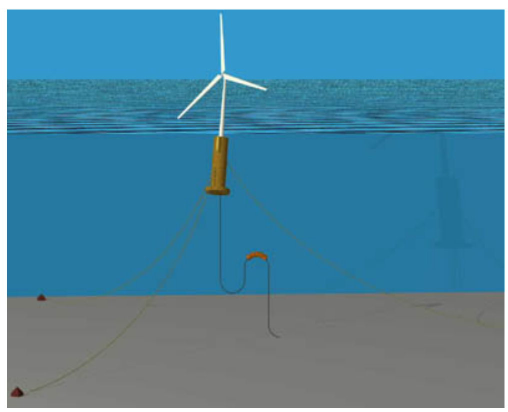
The type of bottom, the water depth, and the expected environmental loads at a prospective location are the major factors that help to determine what type of foundation and support structure will be used for the offshore installation. There are five types of foundations for offshore wind projects: gravity based, monopile, tripod, jacket, and floater. Most offshore wind projects have been installed on gravity-based or monopile foundations, although other bottom fixed types are being used as projects move into deeper water.

Another factor that influences substructure choice is the length of time required for installation. For example if a project has a choice between comparably priced gravity-based and monopile foundations it is likely that monopiles will be chosen. This is because in good weather conditions monopiles can be installed in 1-2 days, whereas gravity based foundations require 5 – 8 days[86]. Figure 2.5 illustrates the different types of foundations.



(a) Tripod Foundation[83] (b) Monopile Foundation[83] (c) Gravity Base Foundation[83]





(d) Jacket Foundation[65] (e) Floating Support Structure[83]

Figure 2.5: Offshore Wind Turbine Foundation and Support Structure Types

<u>*Gravity Based Foundations*</u> - The gravity base is used in shallow water up to about 130 feet[33] and is a concrete structure with a large, flat base. These foundations are easy to manufacture and are good choices in shallow areas with a hard rock bottom although they may require preparation of the seabed such that the top layer of seabed is replaced with an aggregate cushion. In some locations where the bottom type allows, a skirt may be used in lieu of seabed preparation[86].

Gravity based foundations rely on their mass to resist the overturning moment created by the force from the rotating blade and environment. These substructures have cavities in the top-facing side that are designed to be filled with ballast – sand, concrete, or iron ore – after placement on the seafloor. The addition of ballast achieves the required mass, while allowing the structure to be light enough to move onto location.

Monopile Foundations - Monopiles consist of a single tubular pile which is driven into the seafloor and are used in medium depths from 32ft to 130ft[33]. Pile driven foundations have to consider additional geological and geotechnical factors such as resonance. Piles must be driven to a depth that provides suitable stability which will vary by location. For example, in very soft conditions the monopile for the 3 – 3.6MW turbine typically has a diameter of 16.5ft and must be driven 100ft – 115ft into the seafloor[86]. This type of foundation is ideal in clay or sandy bottoms because the pile usually can be driven the entire required depth. In areas where harder bottom types are encountered a combination of pile driving and drilling may be used.

The majority of installed offshore wind projects use monopiles. These substructures usually are constructed of steel, but also may be made of concrete. The use of concrete is cost effective but heavy to transport, and the use of steel is buoyed by experience with previous projects even though it generates more piling noise[33].

Tripods and Tripiles - As projects move into deeper water the use of gravity based or monopile foundations become unwieldy and expensive because of the larger size and increased weight that would be required. Tripods and tripiles have been adapted from the oil and gas industry and expand the footprint of the foundation, spreading the load across a triangular base that is affixed to the seafloor by driving a pile through each of the vertices. They require more time to manufacture and may be difficult to transport, but require less materials. The difference between piles and pods is the manner in which the feet of the structure and support for the tower are connected.

Tripods or tripiles are projected to be suitable for installation in water between 100ft and 165ft deep[12]. Similar substructures can be made as tetra pods or tetra piles.

Jackets - Similar to tripods, jacket foundations are an adaptation from the offshore oil and gas industry. As a result the materials and facilities necessary to manufacture them are readily available. The structure usually has a square base that distributes loads across a broader area and the legs of each corner are connected with a lattice framework. The legs are secured to the seafloor by driving a pile through the foot in each corner[12].

Jackets are suited for use with larger turbines being developed and have been installed to support 5MW turbines[67]. This technology may generate less noise than other fixed bottom substructures, but may be expensive to manufacture and subject to fatigue. They are suitable in depths greater than 130ft[33] where bottom fixed foundations still are desirable.

Floating Support Structures - For United States offshore development it will be necessary to expand into deep water to capture the wind resource many miles offshore, but technology still needs to evolve to be able to accommodate structures at the depths associated with this distance from shore. Floating support structures are being designed and tested to meet this need and several concepts have emerged which adapt floating offshore oil and gas technology for use in the offshore wind industry. These support structures usually employ anchors or suction caissons as the foundation.

Floaters likely will be necessary and most cost effective in water depths greater than 165ft. Test systems have been deployed, but no projects have been installed with floating support structures. The Blue H Group successfully tested and decommissioned a floating tension leg platform substructure in Italy in 2007 and 2008[37] and the Norwegian company Statoil is conducting a two-year test of an anchored, ballasted spar buoy in the North Sea[45].

2.3.2 Turbines

In 1991 the Vindeby Offshore Wind Farm was installed with 450kW turbines and the majority of projects installed in the 2000's have used turbines ranging in size from 2 – 3.6 MW each[25]. Many of the most recent and proposed projects are using 5MW turbines. This illustrates the clear trend in wind turbines to move toward larger, higher capacity turbines that are more efficient.

Moving to larger turbines helps companies achieve suitable economies of scale because it reduces investment costs per kW[70]. These newer, larger turbines are more efficient than the older ones and should correlate to lower operational and maintenance needs (and costs) over the lifetime of the unit[60]. However, this could mean that newer wind farms may be less likely to be able to deal with unexpected events and that if an outage occurs at one turbine a larger percentage of the generating capacity would be offline for projects of equal capacity.

Current ideas being explored may allow marine turbines to transition from the traditional three blade systems to two blade turbines. Three bladed systems have been used onshore to reduce generated noise to acceptable levels, but human noise impacts are not a concern offshore and two bladed systems could achieve suitable electricity generation at a lower cost[20]. Other innovative ideas such as the use of folding blades or direction changing turbines to address issues with tropical storm systems, and integration of turbine components also will lead to more reliable and cost effective turbines.

As offshore wind turbines continue to evolve from onshore turbines new computer models are needed to accurately predict and design for aerodynamics, expected environmental loads, and multiple turbine array effects. The development of more reliable control systems, more efficient blade and turbine control strategies, and power conditioning can increase turbine lifetime, capacity factor, and electricity generation[91].

2.3.3 Reliability

The overall reliability of offshore wind systems needs to be increased as these structures move into deeper water farther from land. Offshore oil and gas installations operate in these challenging environments with less intervention than existing offshore wind structures[96] and many oil and gas installations are manned. Conversely, offshore wind structures do not have personnel on site to address any maintenance or repair issues so they must have a higher degree of reliability to ensure a high degree of availability.

Existing wind turbines have an expected life of approximately twenty years and long-term operation and maintenance needs are closely related to the age of the wind turbine. Since these installations are unmanned, systems that allow remote monitoring, self-diagnosis, and control make it easier to anticipate repair or maintenance needs earlier, reduce mechanical or environmental loads during operation, and minimize effects of extreme environmental events[91]. Additional sensors and smart algorithms can detect developing mechanical problems, help maximize preventative maintenance programs[70], and allow a higher chance that the correct items will be brought onsite to service the machine. This is of key importance since access to offshore turbines requires either boat or helicopter transportation, which is expensive, and may be prohibited for unspecified amounts of time by weather conditions.

2.3.4 Standardization

There is a need to create industry specific standards for offshore wind. Federal and state governments will regulate offshore wind in the United States and the development of consistent standards is imperative. This can be accomplished several ways. Traditional approaches include the creation of rules by a non-governmental standardization body such as the International Electrotechnical Commission (IEC) or the American Petroleum Institute (API), or the federal government can write regulations that can be adapted easily to individual states. Another approach is to task BOEMRE with creating a set of objectives for the industry to meet with regard to electricity generation, structural integrity, and environmental requirements, and then to allow the industry to propose standards and recommended practices. This latter approach is receiving some favor because the offshore wind industry has lower potential for human casualty and environmental pollution than other marine and infrastructure industries and it would allow a more reliable regulatory process to be established expeditiously[57].

Currently, separate standards for the offshore structures and onshore wind industries exist. The difficulty, however, is that they use different models and different reliability standards. The onshore wind industry uses a 50-year extreme condition for determining maximum design loads, but this system only considers wind loading[75]. The offshore structures industry which developed around the oil and gas industry uses a 100-year extreme condition that considers waves and other oceanic contributors to determine maximum design loads, but their models do not include wind generated loads as a large contributor[81]. Note that in the Load and Resistance Factor Design (LRFD) format employed for the design of wind turbines, a load factor is multiplied by a characteristic load associated with a specified return period. It is possible for a 50-year basis to provide similar levels of reliability as a 100-year basis depending on the choice of load factor used in each case and the resulting design load[7]. For offshore wind structures both meteorological and oceanographic factors must be considered when determining extreme loads and models must be developed to predict the loads that will result from extreme environmental events, such as hurricanes, discussed above.

As the industry grows the development of performance and load prediction models, adoption of design requirements and standards, and technological innovations that increase reliability will help reduce risk in and uncertainty about the industry. These advancements also will help to lower costs[91]. Whatever processes are adopted, regulatory bodies and project developers both will benefit from the creation of specific maximum load prediction requirements and uniform standards.

2.4 Logistical Challenges

2.4.1 Installation

Typically installing offshore wind farms can be a lengthy process requiring multiple special purpose vessels. These types of specialized vessels usually have expensive daily rates and require booking a long time in advance of the installation date. Initially offshore wind turbines were installed using existing offshore vessels that assembled turbine sections at the project location. The required vessels included heavy lift vessels with cranes, jack-up barges, and supply vessels built for service in the oil and gas industry. These vessels have the limitation of only being able to carry a few foundations or components for installation and then needing to return to port to load additional pieces. Either additional time per vessel must be allowed or additional vessels must be employed adding to costs and necessitating more difficult logistics.

As the offshore wind industry has evolved different methods have emerged for more efficient and cost effective installation, although many projects still are installed in the manner described above. It has been discussed that it may be possible for some projects to tow whole systems that were built on land to the project site instead of doing in situ piece-meal construction, which would reduce dependence on some of the specialized large vessels.

However, another alternative is to fabricate specific purpose-built vessels for offshore wind, three of which have been built to date. These vessels are able to carry larger numbers of components per trip and do not require the use of additional vessels. The MPI Resolution, for example, can carry up to nine foundations and transition pieces for installation in one trip and then return to port to pick up the nine turbines and towers for installation. In 2010 the vessel installed nine turbines in one week on previously installed foundations[82].
These vessels are heavy lift jack-up vessels with on board cranes and pile drivers that sail to the location, jack their legs into the seafloor, raise the entire ship out of the water and then begin moving and installing components with onboard cranes[82].

Figure 2.6: The MPI Resolution working on location[61]

It remains to be seen whether American projects will be able to employ the existing offshore wind specific vessels as they may be committed to projects in other locations, and are not allowed to work in United States waters on an unlimited basis because of flag state requirements. Whether initially, or after domestic development of industry specific vessels, the use of these more efficient installation methods in the United States could reduce construction delays, overall construction time, and downtime – and therefore installation costs.

2.4.2 Transmission

For offshore wind farms to be feasible the projects must be able to transport power to adjacent shorelines over a fairly direct route and connect into the power grid. Undersea transmission cables and corridors are necessary to transport power from offshore wind power generation sites to energy markets. There are two types of cable used – collection cables within the project area that connect the turbines to offshore substations and the shore transmission cables that run from the offshore substation to the shore connection. Similar to installation of turbines and foundations, the placement and burial of undersea cable requires specialized vessels which may not be available readily and are expensive.

Another major obstacle that offshore wind transmission faces is that the transmission infrastructure in a given area may not be adequate to carry the additional load created by large-scale offshore electricity generation. This has been an issue for onshore wind projects in the United States as well and some states have enacted plans to increase transmission capacity in areas where renewable electricity development is probable. In Texas the Public Utilities Commission has created Competitive Renewable Energy Zones to allow transmission of wind generated electricity from west Texas to more populated areas of the state[23]; however, this investment has not been made yet in coastal areas.

In many coastal areas around the country upgrades to existing infrastructure will be required to facilitate the development of offshore wind. For example, North Carolina's *Coastal Wind* study stated, "Our conclusion is that the transmission infrastructure in…part of the state is not likely to be able to accommodate significant offshore wind generation without significant system upgrades. Interconnection capability without an upgrade is probably in the vicinity of 10 MW, suitable for a pilot wind project, but not a commercial wind farm….[in other areas] indications are that the…transmission system could accommodate up to 250 MW of off-shore wind generation without major transmission upgrades[86]."

2.4.3 Supply Chain

Any offshore project requires substantial supplies, but globally the offshore wind industry suffers from a lack of materials supply, manufactured components, installation vessels, and infrastructure in the face of increasing demands. For a successful American offshore wind industry to grow reliable, domestic supply avenues for transmission lines, turbine structures and blades, platform foundations, offshore vessels, and associated personnel must be developed. The development of a domestic supply chain is key to the cost effectiveness and success of the industry.

The manufacture of wind turbines has been standardized as a result of the onshore industry. Turbines usually are serially produced in pieces that can be transported to the site and then constructed. Several companies, including General Electric and Vestas mass-produce these systems and in the United States these two companies produce eighty-nine percent of all wind turbines[90]. Other European companies have announced plans to build factories in several states[70]. However, difficulties arise for marine turbines made at existing plants. As mentioned previously, offshore systems are moving toward larger turbines, which current plants may not be equipped to fabricate. Even if they can be built at existing plants, these facilities tend not to have access to waterborne transportation routes and increases in component size and weight inland is restricted by highway and rail transportation requirements.

Similarly, serial production of platforms and substructures for offshore installation would help standardize the industry and minimize costs associated with these projects. Despite the potential benefits, actual standardization may be difficult to achieve because of the variation in design parameters required at individual project locations and the increasing size of marine specific turbines. Shipyards and other facilities capable of making components to a range of specifications should be developed.

Project managers are reluctant to invest in the necessary infrastructure because of the existing uncertainties in the industry and lengthy project permitting processes[91]. However, investments in port facilities, installation infrastructure such as specialized vessels, and manufacturing of offshore components near waterborne transportation routes will help lower costs and make offshore wind competitive with other forms of energy. For example, the Virginia Offshore Wind Studies Final Report compared the effect on project cost of using turbines and towers imported from Europe with turbines manufactured in Virginia. The study found that a decrease of $480/kW in total capital costs would result[41].

The development of domestic facilities also would help create jobs in areas that may be economically depressed[91]. NREL estimates that 43,000 permanent jobs and at least 1.1 million manufacturing and installation job-years would be created by the installation of 54 GW of offshore wind[59].

2.5 Summary

The American offshore wind industry faces several technical needs and challenges that must be addressed during the creation of this vibrant new industry. The industry will benefit from additional research and developments that increase reliability, quantification of appropriate design loads, survivability of extreme environmental events, and better project forecasting methods. At the same time issues of logistics, installation, and standardization require resolution as well. In addition, advances in these areas will help achieve needed cost reductions for projects. Numerous entities are working to address these key issues and help ensure that a technologically sound industry emerges.

Chapter Three: Regulatory Issues

Since the offshore wind industry is new in the United States the regulatory system is a work in progress[57]. As is to be expected, with the emergence of a new industry comes the need to structure a regulatory system that is applicable and allows the industry to grow. In the United States this development has been made difficult by the fact that there are overlapping jurisdictions between states and the federal government, and that initially clear legislation did not exist concerning these types of projects.

One of the initial problems with trying to start an offshore wind project in federal waters was that it was unclear who had jurisdiction over such projects. Early attempts to obtain permission in federal waters assumed that the Army Corps of Engineers had jurisdiction under their authority over the navigable waters of the United States. However, the Department of Interior's (DOI) Minerals Managements Service had authority to issue leases for work on offshore outer continental shelf lands. For projects in federal waters the Energy Policy Act of 2005 cleared up the ambiguity by granting DOI the authority to oversee the development of alternative energy projects on the other continental shelf. Subsequently in 2010 the Minerals Management Service has become the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) and they oversee the leasing of the federal outer continental shelf lands.

Remaining regulatory difficulties stem from uncertainty in the level of support for offshore wind from the federal and state governments and a confusing regulatory process where the rules are not yet established firmly. Different governmental bodies are at different stages in the process of enabling offshore wind to become part of their electricity generation scheme.

To facilitate growth in the US offshore wind industry the federal and state governments need to demonstrate long-term support, which can be accomplished in several ways. First, legislation that supports the offshore wind industry must be passed. Second, jurisdictional issues and overlap must be resolved. Third, clear, organized leasing and permitting processes must be established and rules written. Last, cooperation between stakeholders and governmental bodies must be developed.

3.1 Legislation

In order to stimulate growth in the offshore wind energy industry governments must decide that renewable energy is a priority and make a long-term commitment to its growth and integration into their energy portfolios. If the federal and state governments do not make this commitment then investment and financing will remain difficult to obtain. Short-term commitments are not likely to keep support from fluctuating because they do not eliminate uncertainty[96]. For example the short-term stimulus incentives currently in place in the United States may not be sufficient to generate progress in the offshore wind energy industry because of the large investments and time needed to build momentum for offshore projects. Only clear, long-term support can reduce uncertainty and stimulate the industry.

Political support for renewable energy sources has been growing over the last few years and discussion of the best ways to structure incentives for wind power developments have been evolving. However, despite the challenges of increasing demand for electricity and climate change, the United States still has not passed energy legislation that would provide long-term support for renewable energy technologies[9]. Such support could be in the forms of financial or tax incentives, advantageously structured market mechanisms[96], or issuing capacity credits for wind power generation. For example, if a capacity credit higher that 25% is assumed the avoided costs of conventional technologies would increase and wind would become more competitive; if a lower capacity credit were used wind power would be less competitive[60].

3.1.1 Financial Support

The federal and state governments offer various financial incentives for renewable energy projects including tax credits, tax exemptions, loan guarantees, bond programs, feed-in tariffs, cash grants, and performance based incentives. The problem with some of these incentives, particularly the federal incentives, is that they are only offered on a short-term basis. The state incentives vary and are summarized in Appendix One.

On the federal level production and investment tax credits, loan guarantees, and cash grants are available. The production tax credit (PTC) was first created in 1992, and has lapsed three times - in 1999, 2001, and 2003. The effects of the PTC lapses on new wind installations can be seen in the figure below.

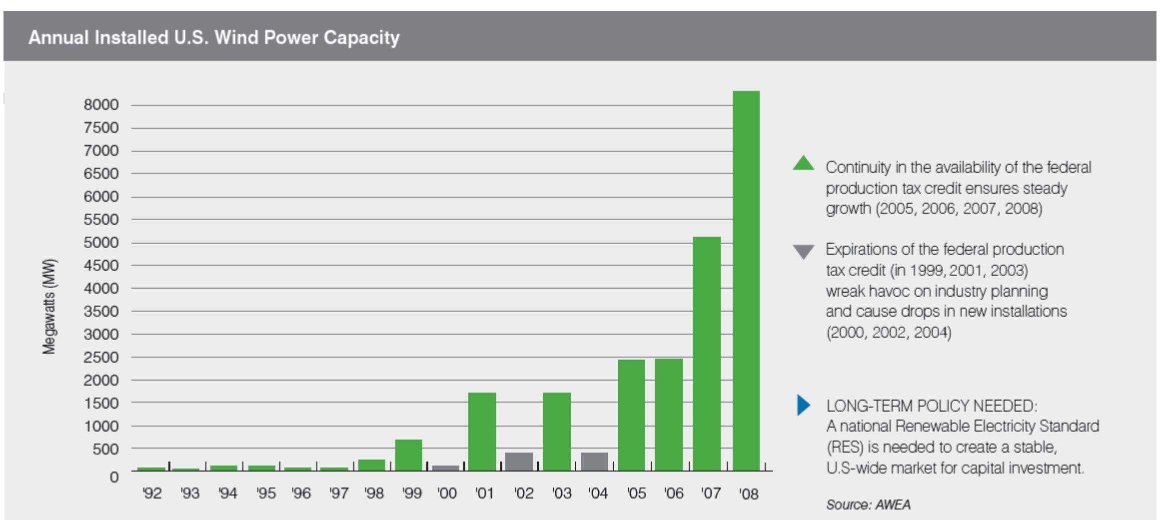


Figure 3.1: Annual Installed US Wind Power Capacity[9]

The current extension of the PTC expires at the end of 2012[9]. The existing investment tax credit (ITC) is authorized through 2013, but eligible projects had to begin construction in 2010[9]. Similarly, the $750 million available for loan guarantees offered through the Financial Institution Partnership Program require that the projects be constructed by 2011[93].

Offshore wind projects take several years to plan and permit. For example, the Cape Wind project took nine years to get final approval[18], and leases offshore Texas allow for five to seven years before electricity generation commences[84]. With projects that require such a long time to develop, financial incentives that expire every few years with no guarantee of renewal make it difficult to assess the economic viability of a project.

We need to pass legislation that creates long-term financial support for offshore wind to help reduce the financial uncertainty that surrounds these projects. In 2010 legislation was introduced in both the US House of Representatives (House) and the US Senate to extend the federal production and investment tax credits for offshore wind energy until 2020[22].

3.1.2 Renewable Portfolio Standard

Renewable portfolio standards are legislative mandates that require a certain portion, as a percentage or specific amount, of a nation's or state's electricity to come from renewable energy sources. It is difficult to measure the precise impact of RPS's, but 23GW of the 37GW (61%) of renewable electricity generation, excluding hydroelectric, installed from 1998-2009 was installed in states with impending or active RPS's[106].

Of the thirty potential offshore wind states, twenty-three have renewable portfolio standards, although the RPS's in Virginia and Alaska are non-binding[106]. The remaining coastal states are mostly Gulf coast and lower Atlantic states where little push for offshore wind development has occurred.

Currently there is not a RPS on the federal level. The Department of Energy developed scenarios to look at what would be required to have twenty percent of the nation's electricity generated from the wind by 2030[89] and two bills are under consideration. The Senate bill proposes a RPS requiring 15% by 2020 and the House bill requires 20% by 2020[9]. Passing a federal RPS would further reduce uncertainty nationwide for renewable technologies, including offshore wind.

3.1.3 Externalities

One of the major benefits of wind power generation, both environmentally and economically, is that it has minimal externalities. If external effects are included in the analysis of costs and in comparisons of various electricity generation sources then wind power has a definite cost benefit because its costs mostly remain unchanged by the inclusion of externalities[60]. Figure 3.2 shows results from different studies that looked at identifying and internalizing the external effects of electricity generation from various power sources and assigned costs to these externalities.

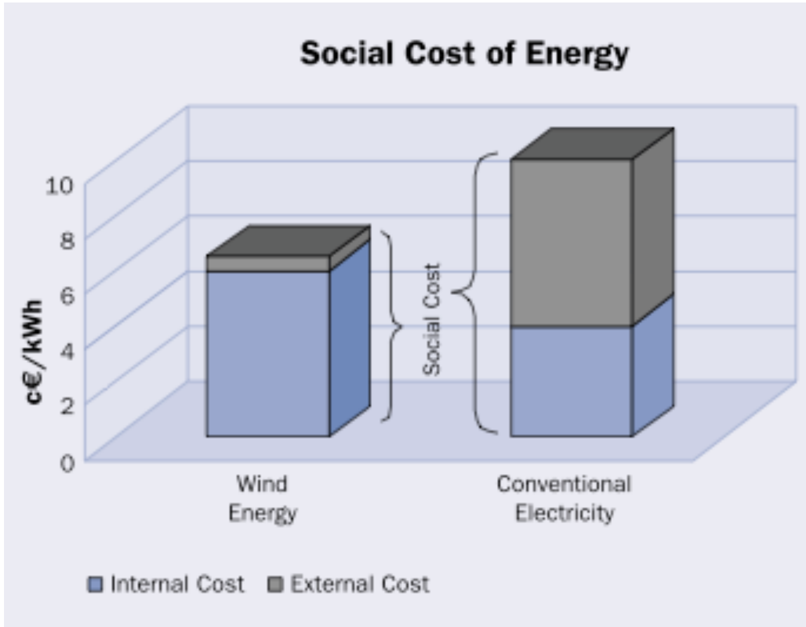


Figure 3.2: The Social Cost of Energy[60]

Information included in the Virginia Offshore Wind Studies Final Report[41], a feasibility study for the Commonwealth of Virginia, illustrates the effect on offshore wind costs of incorporating externalities into the cost of energy. The study found that levelized costs of energy for comparable offshore wind, coal-fired, and combined cycle gas turbine (NGCC) plants were $105-130, $85-100, and $80-100 per megawatt-hour, respectively. When a cost of $50 per ton of carbon dioxide was included the costs for the coal and NGCC plants increased to $135-150 and $100-120, respectively[41]. These numbers show that if the cost of externalities is internalized, the price of offshore wind is competitive with other technologies.

The question is whether or not external costs should be included as part of the analysis of the cost effectiveness of energy technologies. If externalities are included then conventional power generation systems become less competitive than wind power generation systems. Current policies do not include price signals that recognize the value of electricity generated without emissions and this issue has been a challenge across the renewable energy sector[9]. However, Congress is considering this issue and the House has passed a bill requiring the reduction of carbon dioxide emissions[9].

3.2 Permitting and Leasing

As with other types of projects, in order for an offshore wind project to proceed the project must obtain the right to work at the proposed location.

3.2.1 Offshore leases

Before a planned project can proceed the operator must obtain a lease for the surface rights to the proposed location for wind turbine placement from the federal or state government that owns the land. In the United States most states are the subsea property owner out to a distance of three nautical miles and then federal government ownership begins. For Texas and the west coast of Florida the state owned lands extend out to nine nautical miles.

3.2.2 Permits

The Energy Policy Act of 2005 granted the Secretary of the Interior the right to issue both leases and permits for alternative energy projects in the federal waters of the United States. In April 2010 the president announced that BOEMRE had finalized its framework for renewable energy production on the outer continental shelf. The final rule was published in the Federal Register in April 2009[95]. Currently BEOMRE is reviewing several applications and the Secretary of Interior signed the first federal offshore wind permit in October 2010 giving Cape Wind and Associates final approval[18].

Permit requirements in state waters vary by state, but several states are taking steps to support offshore wind power development. Progress toward state leasing and permitting varies, but states have made efforts toward writing applicable regulations, providing incentives, conducting feasibility studies, and identifying areas suitable for offshore wind development.

3.3 Jurisdictional Issues

The governmental body responsible for overseeing the construction and implementation of offshore wind projects varies depending on project location. Each coastal state has leasing and permitting authority for submerged lands out to a distance of at least three nautical miles with the federal government's jurisdiction extending out from the seaward limit of state water to the 200nm Exclusive Economic Zone.

However, to do a project in state water you still must obtain a federal permit, and to do a project in federal waters you usually also must traverse some state waters, except in rare, near-shore federal locations. That means that for projects in federal waters a project still needs a state lease and permits at least for rights-of-way for transmission cables. For example, in states that require permits separate from the federal US Army Corps of Engineers permit prospective developers must go through two separate processes to obtain permission to work on the same piece of land. This is only for projects in state waters. If the project is in federal waters, but must traverse state waters to bring the power to shore they additionally must comply with the leasing and permitting requirements for federal lands.

When initial offshore wind proposals first began for US waters there was some ambiguity regarding offshore wind power and other forms of alternative energies placed offshore. The confusion was between the Outer Continental Shelf Lands Act (OCSLA)[3], which gives mineral leasing jurisdiction to the Department of the Interior, and the Rivers and Harbors Act[1], which gives authority for permitting structures in navigable waters to the Army Corps of Engineers. As a result it was unclear who held leasing and permitting authority. The Department of the Interior and its former Minerals Management Service had leasing and permitting authority for outer continental shelf oil and gas installations, but no stated authority over other types of energy projects. In fact, the Cape Wind Project in near-shore federal waters originally applied to the US Army Corps of Engineers for a permit[87].

In The Energy Policy Act of 2005 (EPAct) Congress settled this confusion. The EPAct amends the OCSLA to state, "The Secretary [of Interior], in consultation with the Secretary of the Department in which the Coast Guard is operating and other relevant departments and agencies of the Federal Government, may grant a lease, easement, or right-of-way on the Outer Continental Shelf for activities not otherwise authorized…if those activities… produce or support production, transportation, or transmission of energy from sources other than oil and gas[2]." This authority, however, begins at the seaward extent of state coastal water.

The Army Corps of Engineers retains its authority in state waters over the navigable waters of the United States under the Rivers and Harbors Act. This statute, paraphrased, says that it is unlawful to build structures in the waters of the United States without recommendation of the Chief of Engineers[1]. This applies to all structures including permanently moored or floating structures and power transmission lines. The term navigable waters means "those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce[1]."

In the case of an offshore wind project in federal waters the Army corps of Engineers is consulted by DoI's BOEMRE during their review of the lease and permit application. State waters also fall within the definition of "navigable waters", even though states have the leasing authority over submerged lands and may have separate permitting requirements. In state waters, applicants must follow whatever process the individual state requires for leasing and/or permitting, and additionally comply with Army Corps of Engineers Rivers and Harbors Section 10 permit requirements

3.3.1 Federal Incentives and Programs

As mentioned above, the federal government offers support of offshore wind development through tax incentives, grants, and loan guarantees that are designed to aid the growth of renewable energy as a whole. The specifics of the federal financial incentives are discussed in Chapter Five.

3.3.2 State Initiatives and Programs

Thirty states have shorelines, including lake coasts, potentially available to offshore wind development. The level of interest and commitment, resource strength, geological suitability, and regulatory readiness varies significantly from state to state.

Individual states have made varying degrees of commitment to renewable or alternative energy sources, including wind –both onshore and offshore. State interest in offshore wind energy has been demonstrated in many different ways. Twenty-three coastal states have established renewable portfolio standards, and thirteen offer financial incentives that are applicable to offshore wind. While many of the incentives are on a smaller scale than federal programs, they can help make projects more affordable.

Several states are working toward collaborative intergovernmental relationships that will aid development of the industry and facilitate leasing and permitting. Others have developed their own industry specific leasing programs, and one has specifically required that a portion of it RPS be met by energy from offshore wind.

3.3.3 Summary of State's Progress by Region

The coastal states easily can be divided into six regions by water body and location. Appendix One displays state specific data relevant to offshore wind development.

North Pacific (Alaska) – Alaska has a non-binding renewable portfolio standard, and offers loan and grant programs that could aid offshore wind projects. However, the state has not been included in current offshore wind resource assessments and no known projects are proposed at this time. It is possible that the geologic considerations or potential for icing paired with the vast oil and gas resources in the state create a lack of impetus for such projects.

Pacific Islands (Hawaii) – Although Hawaii has one of the lowest per capita energy consumption rates in the US, three-fourths of its electricity generation comes from power plants fired by petroleum imported to the islands[32]. The state has both a RPS and financial incentives in place, but while several onshore wind projects have come online, the offshore focus appears to be on the development of wave energy projects[32].

West Coast – The contiguous US Pacific coast has not made significant progress toward developing offshore wind, although all three states have RPS's. The geological characteristics, including tectonic activity and steepness of slope, create additional technological challenges, and none of the state's governments have declared a specific interest in the development of offshore wind. However, Oregon does offer a relevant financial incentive and there is a proposed project using floating foundations in Oregon's waters.

Gulf Coast – Both Texas and the west coast of Florida have jurisdiction out to nine nautical miles. Texas has made significant progress toward developing its offshore wind resources by establishing an active competitive bidding process for offshore wind projects. As of December 2010 the state has issued eight leases[85], and one project received a permit from the USACE and is operating a test platform[102].

Florida is in the process of establishing an intergovernmental task force with the Department of Interior, but it is unclear whether this task force will address its Gulf coast. Currently wind resource assessments are not available for Alabama or Mississippi[78].

Lake Coasts – Several Great Lakes states have been exploring the possibility of offshore wind. These states face some unique challenges stemming from the fact that they would be the first offshore turbines in fresh water and would have to address associated ice issues[81].

Ohio, Michigan, New York and Wisconsin all have conducted preliminary assessments or feasibility studies, and the New York Power Authority is reviewing proposals for projects. In addition, Ohio has written draft rules and created wind turbine placement maps for Lake Erie.

East Coast – Offshore wind projects along the Atlantic coast have been proposed in several states and are in various stages of development. Eleven of the fourteen east coast states have RPS's, and one state, New Jersey, has carved out a portion of its RPS to come specifically from offshore wind. However, only five states offer applicable financial incentives.

In June 2010 the Department of Interior announced the Atlantic Offshore Wind Energy Consortium whose goal is to "promote the efficient, orderly, and responsible development of wind resources on the Outer Continental Shelf[94]." This consortium was established by a memorandum of understanding between DOI and the governors of Delaware, Maine, Massachusetts, Maryland, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, and Virginia[94].

Additionally, the DOI has established intergovernmental task forces with states and other stakeholders to facilitate offshore leasing for renewable purposes. These task forces have been created in Delaware, Massachusetts, Maryland, New Jersey, Rhode Island, and Virginia, and three more states are in the process of forming them – Florida, New York, and South Carolina[94].

3.4 Intergovernmental Partnerships and Cooperation

Intergovernmental partnerships and agreements help eliminate some of the uncertainty in project development that overlaps multiple jurisdictions and spur collaborative efforts between entities with different directives. There have been some key partnerships that will aid the development of offshore wind in the US, although more are needed.

In June 2010 the Department of Energy's Office of Energy Efficiency and Renewable Energy and the Department of Interior's BOEMRE signed a Memorandum of Understanding (MOU) to coordinate deployment of offshore wind and hydrokinetic energy systems on the outer continental shelf. This agreement aims to build collaboration that will aid information exchange, stakeholder engagement, research on issues of mutual interest, development of standards, and information dissemination[51].

The United States Coast Guard is responsible for assessing the effects of offshore wind projects on navigational safety, traditional uses, maritime security and certain natural resources. The USCG and BOEMRE have agreed to a strategy that future offshore renewable energy installation applicants should follow to assess impacts in these areas[16].

Coordination between state and federal regulatory bodies is imperative to facilitate offshore wind leases and permits because of the overlapping jurisdictions. The previously mentioned task-forces and MOU between the DOI and east coast states is a good start toward facilitating projects along the east coast in federal waters under BOEMRE's leasing jurisdiction.   These agreements are a good start, and match with the goals stated in the MOU between the Departments of Energy and Interior. Perhaps future agreements will extend beyond this region as technology develops to allow projects in federal water in other regions.

One key player is not included in these collaborations – the US Army Corps of Engineers (Corps). The Corps must be included in discussions since they hold the permitting authority for structures placed in the navigable waters of the US and must issue permits for project. It may be possible at some point in the future for the Corps to create a general/nationwide permit for offshore wind structures similar to those used for other types of projects like dredging. However, for now, with projects in state waters, either the wind farm itself or the transmission cables, must go through scrutiny separate from BOEMRE and the states.   Collaborative agreements between the Corps, BOEMRE and individual states would aid the industry.

These collaborative efforts are necessary to streamline the evaluations and, hopefully, approvals of offshore wind projects in the future. If additional coordination is not achieved the process will remain difficult to navigate and continue to slow growth of the industry.

3.5 Industry Standardization

Part of structuring the regulatory framework of a new industry is the need to determine whether proposed facilities provide the necessary degree of safety and standardization. As a merger of the onshore wind industry with existing offshore structures there is a debate about the approach to take in writing regulatory standards and how to ensure that they provide appropriate levels of safety.

Existing European projects have been guided by Det Norske Veritas and Germanischer Lloyd – companies that provide classification and insurance for marine interests. However the International Electrotechnical Commission (IEC) has written several drafts of guidelines that attempt to merge these existing standards and other design standards from onshore wind and offshore structures, but their design considerations may not be sufficient for offshore wind regulation in the United States. According to Tarp-Johansen et al. these standards "ensure that the objective of having similar reliability offshore…is obtained if a climate of North European is assumed[81]." The approach does not consider hurricanes, northeastern storms, and fresh water ice pertinent in North America. Clearly, neither approach is sufficient for a US offshore wind standard.

After publishing the final rules for a renewable energy framework the BOEMRE initiated a Joint Industry Project (JIP) to compare existing onshore wind and offshore structural, and proposed IEC offshore standards and examine their differences[47]. This JIP was completed in July 2009, but guidance has not been issued to date.

Ultimately industry standards must be determined in order to provide structured, reliable guidance for offshore wind project developers. The implementation of standard design requirements and level of reliability suffers from the similar issue as jurisdiction stated above. Each state and the federal government have the authority and responsibility of setting the requirements in their respective waters. While in general states are not allowed to set requirements that are less stringent than federal standards, state standards may differ and some states already have drafted rules regarding offshore wind power.

3.6 Summary

Many of the legislative and regulatory issues discussed in this chapter need to be addressed to allow some predictability and reduce uncertainty in this developing industry. If legislation were passed to require the use of renewable energy nationally and/or to place a value on externalities the offshore wind industry would benefit. Even if such legislation is not passed, long-term financial commitments must be passed to allow for proper planning of offshore wind projects.

Additional intergovernmental coordination is necessary for smooth growth of a domestic offshore wind industry. Collaborative efforts will help smooth issues originating from jurisdictional overlap and pave the way for organized leasing and permitting processes.

Chapter Four: Impacts

Various aspects of offshore wind projects have the potential for different impacts. As part of the permitting process proposed projects must conduct risk studies and environmental impact assessments to look at the possible impacts of the project and address these issues. Consideration of impacts, especially environmental ones, is an area where the developing American offshore wind industry can learn a great deal from and build upon experiences of the offshore oil and gas industry and the offshore wind developments in Europe.

The offshore oil and gas industry has had to conduct many studies and collect data regarding impacts. Some of that is not applicable to offshore wind, but much of this research regarding location of projects, certain environmental impacts, potential risk of collision, and multiple use issues is relevant. More research is needed in many areas and the offshore wind industry needs to focus on those potential impacts that have no oil and gas counterpart.

Offshore wind projects usually are looked at as having three main phases: construction, operation, and decommission. The construction and decommissioning phases are relatively short, approximately six months, compared to the estimated twenty-year operational life. Each phase has unique factors that must be considered and while some types of impacts would be present through all three phases.

Potential impacts of offshore wind projects include environmental impacts such as adverse effect to marine fisheries and habitat and avian impacts, noise, visual and cultural impacts, navigational considerations, and multiple use issues. Not all of the potential alterations resulting from offshore wind structures are negative - there also is some potential for positive effects such as the development of artificial habitat and influx of tourism or certain types of recreation at project sites.

4.1 Environmental Impacts

Offshore wind turbines and their associated transmission gear have the potential to impact birds, bats, fish, sea turtles, benthic invertebrates, and marine mammals. Relevant data regarding abundance and patterns of avian and marine species is lacking although here have been several pre- and post construction surveys completed at offshore wind farms in Europe, which have, overall, shown a lower incidence of negative impacts than has been expected by some concerned parties. This lack of data makes determinations about faunal impacts uncertain, and in most areas further data must be collected. Additionally, special consideration must be given to potential impacts on species that are listed as Threatened or Endangered Species including marine mammals, sea turtles, and shorebirds.

4.1.1 Birds

The effects to avian species are of specific concern for the development of the offshore wind industry. Various types of impacts may affect resident and migratory birds, although data showing how far resident shorebirds range over the ocean is sparse. Numerous species of birds spend the summer in North American breeding grounds and overwinter in the Caribbean, Central America, or South America. Migration for various species occurs most months of the year in one direction or the other[41] and the birds use various routes. Some migration routes are completely over land while others are almost entirely over the ocean[64] as shown in Figure 4.1. However, little is known about the specifics of routes over open water[41].

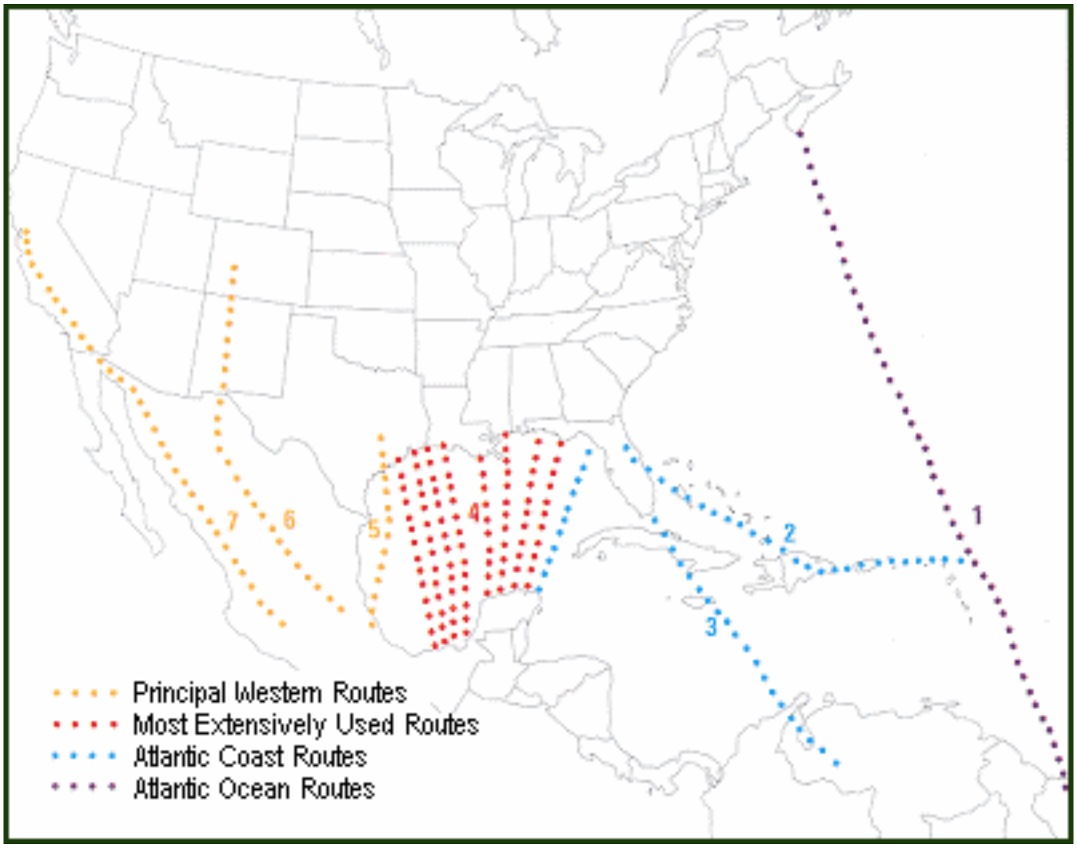


Figure 4.1: Principal Avian Migration Routes[64]

The major avian concerns are risk of collision with the blades by species that do not avoid turbines and that fly in the altitude range swept by the blades, loss or fragmentation of habitat, energy penalties resulting from longer flight paths, and disturbance of migratory patterns[70]. Studies of sites in Europe have not sustained concerns and significant impacts to birds have not been observed. However, it can take years for structures to accumulate prey that attract birds, so they may not be seen in larger numbers for several years after construction has been completed[29]. Species characteristics that contribute to the level of risk include distance flown in the area of the project, frequency of flights, abundance in the project area, flight elevation, and behavioral modifications in response to turbine presence[86], and weather conditions.

The altitude at which birds fly offshore varies based upon several factors: species, weather condition, time of day, season, gender, and age class[41]. The Geo-Marine Baseline Studies Interim Report[38] conducted off the coast of New Jersey using vertical radar and verified with visual estimations showed that birds fly in the altitude range from thirty to 150m, which corresponds to typical altitudes swept by turbine blades[86]. The study area currently is free of wind turbines and it is unclear whether birds will continue to fly at the same elevations in the area if turbines are installed, or if they will avoid the turbines altogether.

A review conducted for the German Environment Ministry summarized avian effect studies which were conducted as pre- and post- project assessments in Europe as follows[27]:

- *Habitat Loss* - "Six species have been found to strongly avoid offshore wind farms. One species showed much lower numbers in wind farm areas after construction than before. Seven species did not show any obvious effects. Three gull species increased in numbers[29]." For the species showing a reduction in number the areal extent of habitat loss was greater than that of the project area. Some species that congregate over shoal areas may be more likely to experience habitat loss[41], but the loss of bottom habitat around the base of foundations appeared to be minimal[29]. Data for additional species is not available predominantly because specimen were not present at the project site often enough to analyze.

- *Barrier Effect* – A "barrier" effect results when birds avoid the project area during flight, particularly during migration. Most of the information available is for migratory species and resident species may interact with wind farms differently within their regular flight paths between roosting and foraging locations. "Eight species have been found to commonly fly detours around, rather than cross, offshore wind farms. Detours were noted for another four species, but it is not clear whether they do so regularly. Fifteen species have been found to fly through wind farms commonly[29]." It is unlikely that small detours around wind farms would significantly increase necessary energy consumption especially in light of the fact that migration distance normally varies with other factors such as weather. Substantial migratory detours or regular deviation of flights between foraging and nesting location of resident species may result in an energy penalty. To date, barrier effects have not translated into significant impact to populations[29].

- *Collision* – The potential for birds to collide with blades exists, and "different types of seabirds have been recorded in mortality studies at coastal wind farms…. However, large-scale mortality of seabirds resulting from collisions with offshore turbines has not been documented in Europe[29]." Although almost no collisions have been observed, definite potential for collision mortality exists.

Some species of birds may be drawn to offshore wind farms while searching for food. This effect may be seasonal and is expected to have the largest impact on species that consume fish[86]. While the potential addition of artificial reef habitat is likely to benefit other types of fauna it could have a detrimental effect on birds because birds that hover at altitude to search for prey may be at increased risk of blade collision, depending on their behavior in response to the turbines. Also some birds may be tempted to use protrusions for roosting or as a perch while hunting. The addition of reef habitat has not been shown to attract seabirds, but it can take a period of years after construction of a structure for this type of attraction to occur[29].

Additional impacts include the potential for energetic penalties resulting from the barrier effect. When birds must fly a more indirect route that increases the distance travelled greater energy reserves are required. Also visits by helicopters and boats during the operational phase may temporarily cause displacement of some species[29].

To minimize potential bird impacts lights required by the FAA to mark aviation hazards should avoid steadily burning lights, and structural projections on towers should be minimized to limit their attractiveness to birds for nesting, roosting, and hunting**.** Also it is possible that the use of contrasting blade colors could help reduce potential collision. The choice to avoid areas typically used as feeding grounds and nesting sites also would reduce the potential for avian impacts[70].

Given the sparse nature of available open ocean data assessment of risk from offshore wind turbines is uncertain and additional studies will need to be conducted to assess the impacts to avian species. As in Europe it is possible that early projects will be required to conduct pre-construction surveys and post-installation monitoring to quantify impacts regarding the loss or shift of habitat, collision mortality, and population demographics.

4.1.2 Bats

While knowledge of avian habits offshore is sparse even less information regarding bats offshore is available. A study by the University of North Carolina at Chapel Hill assumes that the risk to bats from offshore wind turbines decreases with distance to shore because bats depend upon terrestrial resources[86]. However, where risk to bats does exist potential impacts include mortality resulting from air pressure differentials in vortices downwind of the blades and collision with turbines.

As with birds, it is possible that some species of bats might be attracted to wind farms while searching for food. In 2007 Ahlen et al. documented that the white color of Swedish wind turbines installed 14km to sea attracted insects, which then attracted bats to prey upon them[8]. This scenario could be avoided by painting turbines colors that do not tend to attract insects.

4.1.3 Fisheries

Offshore wind turbine structures have a small footprint on the seafloor and tend not to have large amounts of exposed underwater gear. Therefore, long-term impacts such as habitat loss and fragmentation have not been observed. Despite this, potential for both negative and positive impacts to fish exist. Negative impacts can include vibration effects, electromagnetic effects, and water current changes, and physical displacement. Positive impacts include the creation of additional habitat and possible sanctuary from heavy fishing.

Noise associated with pounding of foundations during installation and vibrations resulting from normal turbine operation both can be transmitted into the sediments and water column at the project site. It is possible that strong vibrations or specific frequencies could disturb fish and may negatively impact spawning for some species.

The electrical connection cable and equipment necessary for offshore wind projects may disrupt navigation in species of fish that use Earth's magnetic field[70] leading to a disruption of feeding or migratory behavior[43]. Conclusive evidence either way does not exist, but this concern usually is minimized by using certain types of cables and burying the cable into the seafloor[29].

The installation of offshore wind turbines and their scour protection can cause small, local changes in water flow characteristics through the project area. Adequate turbine spacing can minimize these changes, but water current disruption could alter the feeding and migratory behavior of fish. These disruptions may be more prevalent in younger fish and larvae[29]. Additional study is needed to address this concern as well electromagnetic concerns mentioned above.

Physical disturbance of fish results from removal of substrate, site preparation, and installation of foundations at the project site[43]. This type of disturbance is short-term and usually is outweighed by the positive effects that result after construction when the site begins to act as additional habitat.

Potential positive impacts exist. For example the North Carolina study found that, "…as air flow passes through the spinning blades of the wind turbines, a divergence of winds is created over the water surface[86]. This atmospheric phenomenon itself induces local upwelling whereby deeper waters are brought to the surface. In [areas] where bottom waters can become oxygen depleted during summer and can even cause fish kills, wind turbine-induced upwelling and vertical mixing would reintroduce oxygen and thereby have beneficial impacts…because it brings deeper nutrients into the lighted surface waters and thus enhances phytoplankton production, on which the pelagic food chain is based[86]."

Willhelmsson et al. documented that monopile foundations off the coast of Sweden had been colonized by mussels and fish normally associated with reefs[101]. This finding is in line with artificial reef programs, such as the Texas Department of Parks and Wildlife's Rigs to Reefs Program, which use the support structures from offshore oil and gas facilities to create fish habitat at otherwise barren locations on the seafloor[74]. The bases of offshore wind turbines could provide similar habitat, feeding areas, spawning grounds and nurseries, shelter from predation, and sanctuary from intensive fishing.

4.1.4 Sea Turtles

Six of the seven species of sea turtles range in United States waters and/or nest on American beaches. All six species are listed federally as threatened or endangered[46]. It has been documented that one species is attracted to offshore oil and gas structures[53] and it is reasonable to anticipate their attraction to offshore wind structures. Other species may hibernate in sediments in or near project locations. Also there is potential for the lights on turbines or electromagnetism from project components that may affect sea turtle navigation to distract nesting females and hatchlings moving to and from nesting sites. In general, while these concerns exist the potential for direct injury is low[86].

The highest risk to sea turtles from offshore wind projects is the risk of mortality from trawling activities if trawling is allowed within the project area[41]. It is likely that at least two species will be attracted to offshore wind turbines to forage on mussels or crabs that colonize the project and other shrimp and commercially valuable fish also may be attracted to the project site[86]. If trawling is not allowed that projects may provide some degree of sanctuary for the turtles in the project area.

4.1.5 Benthic Fauna

The placement of turbines results in a localized change in bottom habitat where the foundations are installed because of the replacement of soft bottom with the hard substrate used for scour protection and the foundation itself. As a result, some buried fauna would be replaced with epifaunal invertebrates that attach to hard substrate[86]. While the introduction of hard substrate can aid in artificial reef establishment[29] as has been documented in Sweden[101], it also can facilitate colonization by invasive species[86].

The installation of collection and transmission cables associated with the project would impact infaunal species. These impacts would be short-term and the sediment-living species should recover quickly after installation and cable burial is completed[41].

4.1.6 Marine Mammals

Numerous species of marine mammals are found in the coastal waters of the United States and are protected under the Marine Mammal Protection Act. Similar to fish, marine mammals are susceptible to disturbance by noise from the construction, and are potentially susceptible to impacts from operational noise and possible interference with their internal magnetic compasses[70]. At this time the effects of the low frequency vibrations resulting from turbine operation or electromagnetic fields are uncertain.

Vessel collisions and construction noise from pile drivers have the largest potential to impact marine mammals. These hazards can be mitigated successfully by employing submarine acoustic pingers[24]. Such alarms emit noise on multiple frequencies at initially low levels and gradually increase the signal strength to entice sensitive species to temporarily leave the area. The success of these deterrent methods, as well as susceptibility to the noise, varies between species.

Studies of possible marine mammal impacts from offshore wind installations are in progress by the wind industry and conservation groups[9]. In particular further study regarding the impacts of construction noise and the effects of operational vibration transmitted into the water column will help ensure that marine mammal impacts are adequately mitigated[70].

4.2 Noise

Noise disturbance to humans has been an issue with onshore wind turbines, but is not a significant issue offshore. As discussed above, suggestions have been put forth that offshore wind turbine noise could travel underwater, affecting marine life, but available data is insufficient to assess this risk

Noise associated with pounding of foundations during installation temporarily impacts numerous species. The successful use of acoustic pingers minimizes this impact by motivating sensitive species to temporarily leave the area prior to the commencement of work.

4.3 Visual and Cultural Impacts

Whether the visual change to a coastline that results from the installation of offshore turbines is positive or negative depends on individual viewpoints. State laws vary regarding the assessment of visual impact and the rights of property owners adjacent to a project site. The extent to which offshore wind turbines are visible depends on the height of the observer, the height of the turbines, the distance that the turbines are placed from the shore, and the geometry of how these factors interact with the curvature of the earth.

Aesthetic impact can be defined as "degrading [of] visual quality through significant alteration of the natural features of vistas and view points[66]." The problem, however, is that standards such as this are subjective. Attempts have been undertaken to make assessments of aesthetic impacts objective but the translation from subjective to objective is difficult. Questions persist about whether it is better to leave the determination subjective or rely more heavily on computer models and calculations of percentage of a view that is changed[66].

Most potential cultural impacts are closely related to aesthetics since aesthetics are one of the major considerations when determining whether locations of cultural value are impacted. Cultural sites can include historical landmarks, tribal grounds, and national/state parks and seashores. Disturbance of archaeological sites also could provide a cultural impact, but proper placement of project equipment and the use of buffer zones can eliminate the potential for disturbance of known sites.

Offshore wind projects suffer from a concern about the depreciation of coastal property values for properties from which the projects would be visible. This concern has not been validated by corresponding decreases in property value in Europe where numerous projects have been constructed. Similarly, a Department of Energy study of land based turbines vs. property value concluded, “Neither the view of wind energy facilities nor the distance of the home to those facilities was found to have any consistent, measurable, and significant effect on the selling prices of nearby homes[88]”. On the contrary offshore wind turbines have the potential to attract tourists interested in the projects.

While public opinion differs on this matter it is fair to say that people are a “wild card” in trying to assess the impacts of offshore wind projects. During consideration of these projects the potential for visual and cultural impacts cannot be ignored.

4.4 Navigational Considerations

The development of offshore wind projects has the potential to impact shipping and air traffic. In the United States the Federal Aviation Administration (FAA) and the

United States Coast Guard (USCG) are tasked with ensuring the safety of aerial and marine navigation, respectively, and these agencies will have to evaluate the potential impact to navigation of proposed offshore wind installations. It will be necessary to coordinate with the United States Coast Guard (USCG) to ensure proper placement so that turbines are not placed in shipping lanes and will not interfere with routine traffic. The USCG also has the responsibility for assessing impacts to "traditional uses of the particular waterway"[16], search and rescue operations, and marine pollution.

Assessment of impacts to marine navigation must consider several aspects including wind farm proximity to shipping routes, proximity to other wind farms and structures, relative depth of waters adjacent to the project, traffic density in the area, and the possibility of collision[26]. Similar to consideration of delicate ecological sites, proper considerations for locating offshore wind farms are important for the minimization of navigational impacts. These impacts can include radar interference, changes in the effectiveness of marine electronics, and increased risk of collision.

4.4.1 Marine Electronics

Concerns have been raised about offshore wind turbine impacts to marine electronics, communications, and compasses. The UK Maritime and Coastguard Agency (MCA) conducted sea trials in the vicinity of the established North Hoyle offshore wind project to assess the potential impact to the safety of navigation, search and rescue operations, communications systems, ship borne and shore-based radar, vessel automatic identification systems, position fixing equipment, and magnetic compasses. The findings regarding radar will be discussed in the next section.

This study found the impacts to all studied marine electronics, except radar, to be minimal and concluded that the project does not adversely affect navigational safety. The study does note that there is a shadow zone behind turbines that affects line-of-sight VHF communications, and that this shadow is larger the closer the vessel is to the turbines. The study was not able to assess implications to search and rescue operation and associated short wave radio because these asses were diverted at the time of study[44].

4.4.2 Radar

Both the Federal Aviation Administration (FAA), the UK Maritime and Coastguard Agency (MCA), and the British Wind Energy Association have conducted studies regarding offshore wind turbine effects on radar. The FAA study looked at potential impacts of the Cape Wind project on air traffic control and primary and secondary aeronautical radar[42]. The MCA studied radar as part of the North Hoyle study mentioned above[44] and the BWEA study examined radar issues near the Kentish Flats project in the UK[56]. Each of these studies shows that wind farms affect marine and aeronautical radar and it effectiveness at target detection and tracking.

The extent to which wind farms impact radars is related to the proximity of the radar to the wind farm. When turbines are close they return very strong responses which generate side lobes and multiple or reflected echoes as shown in Figure 4.2.

Figure 4.2: Spurious Echoes Near Kentish Flats Offshore Wind Farm[56]

These can make the radar display appear smeared and interfere with proper operation of automatic target tracking. It is possible to turn down the gain, or sensitivity settings, on radar which usually will resolve the side lobes and reflected echoes, but lowering the sensitivity of the radar increases the chance that smaller and more distant targets will not be detected. On a positive note, the results of the MCA study showed little evidence of targets physically being shadowed by turbines[44].

Of particular concern for aeronautical radar is the fact that primary radar detects the turbines and, because of the movement characteristics of the blades, classifies them as airborne targets. Secondary radars, which interrogate transponders on aircraft, may be affected by the blockage of interrogation signals. Despite these radar effects the FAA concluded that there were "little or no noticeable impact[42]" on primary or secondary aeronautical radar [operations] except that some fading of radar signals would result at lower altitudes, and that "It is unlikely that these misses will impact air traffic operations[42]."

In general impacts to ship and shore based radars and aeronautical navigation may be minimized and the MCA does not expect that these effects will compromise maritime safety and navigation[44]. The upgrade or relocation of radar resources may be necessary to minimize impacts. For example the FAA is requiring Cape Wind to upgrade nearby radar installations[42]. Additionally the FAA will require warning lights on turbines, particularly those near airports[70].

4.4.3 Risk of Collision

The installation of offshore structures, generally, increases the risk of collision with said structures. This increase may result from the physical presence of the turbines, affects on collision avoidance equipment, increase in vessel density, or the re-routing of vessel traffic.

As explained above offshore wind turbines can impact navigational radar and in the North Hoyle study MCA concluded "[M]ariners will need to pay particular attention to the determination of a safe speed and to assessing risk of collision when passing near or through wind farms, particularly in restricted visibility[44]." When passing near offshore wind farms mariners will need to be aware that their automatic radar plotting aids may not work correctly and that if they adjust the radar gains potential targets may go undetected. As mentioned above other impacts to marine electronics are minimal.

To alleviate risk of collision structures built at sea are required to submit information to the Coast Guard so that it may be disseminated to mariners via Notice to Mariner publications that issue corrections for existing charts. The position of the project also will be included on new chart editions. This process is well established and enables mariners to avoid obstructions. Offshore turbines also will be required to display proper navigational markings, lights, and fog signals. These measures should allow offshore wind farms to be identified and avoided.

Re-routing of vessel traffic may increase traffic density in some places[26]. A navigational risk assessment conducted for the proposed Hong Kong project in some of the most densely used waters in the world found the increased annual risk of collision to be 0.3 incidents and that this corresponded to an additional fatality risk of 1 in 300 years[15]. Depending on the needs of the location vessel traffic in proposed offshore wind project areas may be re-routed using exclusion areas or traffic separation schemes which would aid the safety of navigation[26]. The employment of these measures will require assessment of traffic patterns on a larger scale to ensure that measures are not piecemeal.

4.5 Competing Uses

The development of offshore wind farms has to potential to conflict with other ocean uses. Some areas will be incompatible with offshore wind development while in others the greatest benefit may be provided by the installation of offshore wind turbines.

4.5.1 Navigation Lanes

Shipping corridors and traditional routes designated on charts that are regularly used by commercial, military, and fishing vessels are not compatible with wind farms. It is probable that a buffer will be required around these areas to allow additional sea room for maneuvering, but that determination will have to be made by the Coast Guard.

Outside of these shipping lanes vessels that traditionally transit through the site of a proposed wind farm may have to be re-routed, depending on whether vessel traffic is generally excluded from the project site and the class of vessel. Re-routing of vessel traffic may mean that vessels incur some time penalty and additional cost for fuel by taking a different route.

4.5.2 Fishing

The extent to which fishing activities conflict with wind farms largely depends on the type of fishing and associated gear. If fishing of various types is allowed within the project area the potential for collision with a turbine or fouling of fishing apparatus on turbines exists. Commercial fishing that uses bottom dragging gear such as dredges and trawling gear are incompatible with offshore wind farms as they have to potential to foul the transmission and collection cables necessary for the project. Other types of fishing are unlikely to conflict, such as trolling, trapping, and setting of gill nets. Recreational fishing does not employ gear that would jeopardize wind farm assets.

4.5.3 Recreational Uses

Activities such as boating, diving and sailing may or may not be compatible with offshore wind structures, largely depending upon type of vessel and the skill of the operator[86]. Smaller vessels should be able to maneuver between turbines and the tendency of offshore structures to attract marine life may enhance diving opportunities in the area.

4.5.4 Special Areas

Possible multiple use conflicts exist in the following areas:

- *Dumping Grounds and Anchorages* – These special use areas, particularly military ordinance disposal sites, are incompatible with the development of offshore wind unless turbine spacing allows enough room for the required vessels, such as those engaged in dredge material disposal, to work within the farm[86].
- *Mining sites* – In areas where active sea floor mining for sand or other minerals occurs use conflicts may arise.
- *Marine Protected Areas* – These areas protect specific resources in various ways and are designated on nautical charts. They are likely to be incompatible with offshore wind.
- *Archaeological Sites* – Cultural and historical sites can be protected by sharing information about their location and designating buffers.
- *Air Traffic Control and Military Use Zones* – In near-shore areas locations may exist where installation of wind turbines conflicts with civilian or military air traffic or military operations and training locations.

The degree to which multiple use conflicts affect the possibility of offshore wind development will have to be assessed on a site-specific basis. The determination of whether an offshore wind farm will become an exclusion zone for certain types of fishing, such as dredging and trawling, or may be closed to all vessel traffic not associated with the project largely will determine the extent of these conflicts.

4.6 Summary

The development of offshore wind projects has potential impacts, although many of the quantified effects can be suitably minimized or mitigated. Issues exist where evidence is sparse and additional study is required. This is a particular issue where faunal impacts are concerned and the degree of impact is unknown. Areas where determinations of risk are uncertain will benefit from the completion of baseline studies prior to construction and comparison with post-installation assessments.

Each offshore wind project that is proposed will have to complete site-specific examinations and an environmental risk assessment prior to approval and construction. Consideration of factors prudent to choosing a proper project location will minimize conflicting uses and aid in project approval.

Chapter Five: Finance

Capital costs for offshore projects are higher than those for onshore project although they represent a lower percentage of the total project costs for the life of the project. In the current economic climate the high costs are limiting the availability of financing[96]. The constriction of financing availability causes delays to projects and may cause the abandonment of some projects.

Offshore projects have higher operation and maintenance expenses, more costly construction and installation, and require more expensive pre-project assessments and surveys than comparable onshore projects. Add in access challenges, weather delays, possible technical problems, storms, and unclear permitting requirements and one can see that there also is a large amount of uncertainty and risk as well.

In order for offshore wind projects to be economical they generally must be large scale which requires a considerable expenditure of capital[80]. High capital costs and expensive operation and maintenance costs equal sensitivity to the amount of equity available and the cost of capital. Pair this sensitivity and cost with the youth of the industry and degree of uncertainty, and the result is that there is no set formula for financing of offshore wind power projects. Each of the existing European projects has a unique monetary structure and many factors vary depending on the incentives available.

5.1 Costs and Uncertainty

Offshore projects must be large in order to obtain a suitable economy of scale because the costs for turbines and towers, vessel rent, project installation, subsea collection and transmission cables, and operation and maintenance all are high. It is possible that economies of scale at large project sites could be achieved with lower costs as the industry moves to larger, more efficient turbines. Morthorst has estimated the average costs of producing wind power in coastal areas is between 6 to 8.3 cents/kWh and that this cost could be reduced to 4.7 to 6.6 cents/kWh in the near future[60].

In addition, costs vary substantially from location to location and generally increase with increasing distance to shore and water depth. All of this illustrates the difficulty in estimating general project costs for offshore wind power projects. The major costs of offshore wind projects are of two types: capital costs, and operation and maintenance costs. Here we briefly will discuss the impact of external costs and uncertainty as well.

5.1.1 Capital Costs

One of the major issues with financing an offshore wind project is that these projects are very capital intensive and as a result, the availability and cost of capital can be significant barriers to entering the industry. As with many renewable energy technology projects the capital costs for wind projects are the majority of the total costs. This occurs because wind, solar, and geothermal projects cost money to build but do not require costly fuel purchases to operate.

Capital expenditures are divided easily into several categories. First, surveys must be performed to ensure adequacy of the location and define technical parameters. These surveys include site investigation, geotechnical analysis, and project design. Second are the costs of obtaining offshore leases, permitting, and environmental assessments. Third, the physical infrastructure makes up the majority of costs and includes the costs of the turbines, foundations and support structures, electronics, subsea cables, and grid connections. Fourth, construction costs are significantly higher offshore because of the nature of the marine environment and the need to hire specialized work vessels. Last are the expenses associated with obtaining financing and loan guarantees. Table 5.1 shows a breakdown of capital costs by category.

Table 5.1: Comparison of Onshore and Offshore Expenditures by Category[17]

Cost Category	Offshore Percentage (%)	Onshore Percentage (%)
Turbines	45	64
Support Structure	25	16
Grid Connection	21	11
Project Management	2	9
Installation	7	--

Approximately seventy-five percent of the total costs for onshore wind projects are capital costs to cover the physical infrastructure and construction. For offshore developments this percentage falls to approximately sixty percent even though additional expenditures such as subsea cables and marine construction are required[60]. Although the capital costs for an offshore project are a smaller percentage, the actual amount of capital needed is higher, owing to the substantially higher total costs.

5.1.2 Operation and Maintenance Costs

The costs for maintenance and operation of offshore wind projects are high because of access challenges and the nature of marine environments. These costs increase over the life of the turbine, and although manufacturers initially cover the cost of turbine repairs, the operator's maintenance costs start to increase after the initial period and as the project ages repair needs will increase, requiring reinvestments to maintain the project[60]. The major variables that drive this increase are vessel rent and the cost of offshore labor and equipment.

5.1.3 Externalities

Wind power generation has very few externalities, which is a strong plus over conventional fossil fuels. Those that it does have result mainly from the manufacturing, transport of components, and installation of the turbines and associated equipment. However, the environmental damage and greenhouse gas emissions of conventional power generation currently are not considered in cost analyses[19].

The current policy debates, which were discussed in chapter 3, about whether external costs should be included, and consideration of carbon emissions taxes and cap and trade systems could result in price signals that recognize the value of clean power generation. The inclusion of externalities would affect the cost analysis for wind power projects positively because their costs remain mostly unchanged by such inclusion[60]. As a result, the inclusion of externalities would not create additional uncertainty in the offshore wind industry as it would in other electricity generation industries.

5.1.4 Uncertainty

Difficulties in obtaining financing for offshore wind projects because of high capital costs are exacerbated by the youth of the industry and level of uncertainty associated with these projects. Even though the industry has been developing for the last twenty years offshore projects are viewed as risky. The wind industry in general is transforming quickly and no one technology has proven the ability to operate effectively for a multi-decadal period of time, so the technology is viewed as marginally proven by financiers. Indeed some of the technology necessary for American offshore wind power still is being developed. The foundations and moorings for projects to move into deeper water currently are being tested, and advancements are needed to increase resistance to storm damage, predict appropriate design loads, enhance remote monitoring, and increase reliability.

The total cost of offshore projects is between 30 and 80 percent higher than onshore projects of comparable capacity depending on the specific offshore location[80]. As mentioned above costs vary significantly from site to site because of the differences in technical requirements, depth, and distance from shore at each location. It is difficult to make one template for an offshore wind power plant and apply it to multiple locations, which in turn makes it difficult to apply costs across projects, although chapter six is attempts just such cross project cost application.

Large utility companies initially were the primary developers of offshore projects in Europe and they constructed these projects without external funding. However, this meant that they carried the full burden for the project's risk and after problems were encountered with some large offshore projects, single developers became unwilling to underwrite offshore wind farms. "Offshore installations are considerably more expensive to construct and maintain than onshore, and the sector has a limited track record with some significant failures[80]." The most notable failure occurred at the Horns Rev Reef project in the North Sea where Vestas had to dismantle all eighty-one turbine nacelles and send them to shore for repair less than two years after their installation[97].

Government policies also create uncertainty, particularly in the form of short-term commitments[96]. The United States government offers some support via loan guarantees for renewable power financing, but the program is only funded for projects constructed through 2011[52], and Congress has not passed a long-term national renewable energy standard. Here offshore wind power development has not occurred yet. In contrast, the European Union has made policy decisions, such as the Greenhouse Gas Emissions Trading System that favor renewable electricity generation and some national governments such as the United Kingdom specifically support development of offshore wind projects. As a result numerous offshore wind projects have been constructed and in [2008] the European Investment Bank (EIB), the lending arm of the EU, began to provide project financing[14]. If the federal government and individual states would pass legislation providing long-term commitments, as discussed in chapter three, uncertainty would be reduced.

Supply issues and weather delays, both of which can cause the project to fall behind schedule, generate additional uncertainty. Increased demand for turbines causes pressure throughout the material supply structure[28] and can lead to price increases as manufacturers scramble to meet demand. The rate to hire offshore vessels and their availability can have a huge impact on a project and weather can cause delays during construction and maintenance trips. According to Douglas Westwood and Associates there was a 250% increase in costs of European offshore wind projects in the six-year period from 2003 to 2009, because of the prices of oil, steel, and vessel rent. Fortunately for offshore wind, these costs currently may be depressed because of the recent global financial picture[96].

5.2 Financing Structures

The manner in which risks are assessed and projects are funded has shifted as a result of the uncertainties- especially construction and repair issues. Instead of single-party funding, the prominent funding mechanism is project financing through commercial lenders using multiple contract facilities that involve manufacturers, utilities, operators, banks, and investors. “Multi-contract structures… are slowly taking shape for the next generation of projects[80].”

In some instances lenders are taking more conservative financial positions in an attempt to limit risk. This can be done by applying a higher discount rate or setting more conservative reserve-base borrowing guidelines. As will be demonstrated in Chapter Six variation of the discount rate has a real impact on project economics. Morthorst showed that if the discount rates were doubled from 5% to 10% per year in coastal areas where costs range from 6 to 8.3 ¢/kWh a 2.3 ¢/kWh cost increase would result[60].

Increases in reserve baselines require the developer to have more equity. Both of these approaches to limit risk can widen the gap between available equity and debt for a given project and increase the cost of capital. As a result these increases in cost limit the availability of financing.

In some cases banks are willing to finance only a portion of the money required in addition to equity and project planners are forced to find ways to bridge the funding gap. These methods can be private or government funded. Government options can include capital investment grants, tax incentives, or subsidies for generation. Private options include types of private placement such as mezzanine funding and private equity investments. It is common to use equity kickers in the course of funding offshore wind projects in other countries, but this is not permissible in the United States.

Financing of offshore wind projects does not always encompass the same things in different locations, or have the same financial products available. Individual states offer different incentives, and have different renewable power requirements as shown in Appendix 2. Different utilities and power grids may have different requirements.

Each project has a unique funding structure. As mentioned previously, for offshore wind projects to achieve a suitable economy of scale the projects must be quite large and therefore are expensive. In order to interest banks and investors in the large-scale financing of these relatively risky projects the return on investments has to be attractive and suitable contracting structures must be developed[80].

A given offshore wind project in the United States may be funded by using a combination of any or all of the following financial products.

5.2.1 Direct Funding

As mentioned above, offshore wind projects in Europe initially were wholly funded by the developing company or utility. As projects have gotten larger and more expensive funding has shifted to commercial financing.

5.2.2 Non-Recourse Loans

Most existing offshore wind projects are financed with non-recourse loans where the project is put up as collateral, but the borrowing entity is not liable for losses in excess of the value of the collateral. This means that the lenders must rely on the project's revenues to repay the principal and service the interest costs with little, if any, additional support.

5.2.3 Syndicated Bank Loans and Joint Ventures

As a result of the high degree of uncertainty many recent offshore wind projects have been financed with syndicated bank loans. One bank or a group of banks will act as the Lead Arranger and coordinate with other investors who then use their combined ability to obtain funding, or in the case of banks, to give financing. This allows these entities to minimize risk by spreading it out and raises funds quickly[54].

5.2.4 Private Placement

Wind power developers seek to lower the cost of capital and overcome the gap between available equity and bank financing by raising private equity funds or using mezzanine financing or a mezzanine facility. Private placement allows for direct investments from sophisticated institutional investors without regulatory oversight[55]. Private equity funding may not be as cost effective for the developing company as using a mezzanine facility because private equity investors typically expect a twenty-five to thirty percent rate of return while mezzanine lenders usually expect eighteen to twenty percent[11]. This twenty percent return can be all cash paid interest or can be a lower percentage cash payment paired with other incentives that make up the difference.

Mezzanine debt usually is subordinate to bank financing, such as syndicated bank loans, is non-recourse and usually matures in two to five years. Mezzanine facilities are "...layered between senior debt and equity in the borrower's capital structure...[11]" This type of financing also can increase the total amount of capital available because the total debt available from private placement and bank financing could be higher than what the bank is willing to finance, even if the bank decreases the amount it is willing to lend as a result of the use of mezzanine facilities.

5.2.5 Government Assistance

To help make the numbers sum appropriately for offshore wind projects governments provide several incentives to spur funding and development[50]. Most of the incentives exist for the renewable sector as a whole, not solely for offshore wind. Government incentives can take several forms including loan guarantees, grants, tax credits, bond programs, and feed-in tariffs.

5.3 Current Government Assistance Programs

Several federal and state government programs and incentives are in place that can be used to help finance offshore wind projects in the United States. In addition, states may offer specific incentives for projects in their waters. While, in general, state incentives tend to be for smaller amounts than federal ones, both can help make offshore wind projects more economically viable. The federal incentives are discussed below and state incentives are summarized in Appendix 2.

Loan guarantees help secure funding and lower the cost of capital. Such programs aid to pay for credit subsidy costs of loan guarantees for commercial generation projects. The United States has funds amounting to $750million to pay for the closing costs and other costs associated with initiating project financing. The federal loan guarantee is available through the Financial Institution Partnership Program and the Department of Energy[52]. This guarantee is for renewable energy projects that are constructed by 2011.

Production and Investment tax credits lower the recipient's tax burden[50]. These types of credit are appealing to investors who have high taxes on other projects and wish to lower their overall tax debt[99]. A production tax credit is based on the amount of electricity generated and lowers the cost of the project, but not the price. The current production tax credit (PTC) available for renewable energy production is 2.1 cents per kilowatt-hour generated and is available through the end of 2012[9].

Investment tax credits, which are equivalent to a specified percentage of the project's cost, usually are spread over a period of several years and help lower costs[99].

Grants can take different forms. They may be set up to pay a percentage of a project's costs or help pay for specific aspects of a project. Grants lessen private up-front costs for project developers[50]. Currently the US Treasury is offering cash grants to pay a percentage of overall project costs in lieu of an investment tax credit[99]. The grant actually converts the ITC into a single cash payment. These cash grants were authorized through 2010 and have no guarantee of renewal.

Feed-in tariffs are subsidies that guarantee payments for electricity sales and are designed to provide a predictable level of revenue for the project[50]. Usually the price guaranteed is higher than the market rate for electricity[28]. These tariffs allow project planners a degree of certainty that can be used to more accurately estimate revenue and make decisions about costs of the project. Government feed-in tariffs are not offered on the federal level, but private purchase agreements between projects developers and utilities achieve the same end.

These incentives help make the cost of offshore wind more affordable, but they are not long-term commitments. Since offshore wind projects take a considerable amount of time to development these short-term, sun-setting incentives do not help lower uncertainty for these projects. For example in the ten years that Cape Wind has been working to get to the construction phase[9] the production tax credit has been allowed to lapse twice. Additionally, if the project does not begin construction by the end of 2010 it will no longer be eligible for a cash grant[9].

5.4 Highlighted Project Finance Structures

5.4.1 Princess Amalia

The Princess Amalia Wind Farm in the Netherlands won a Deal of The Year Award in 2007 from Euromoney and Project Finance Magazine for its innovative financing structure[69]. The total investment cost was $513 million which was financed on a non-recourse basis by leading banks Dexia Group, Rabbobank International and BNP Paribas. The Dutch export credit agency, Eksport Kredit Fonden (EKF), participated in the financing since the turbines will be supplied by the Dutch company Vestas[97]. The project was funded out of the following: equity and subordinated debt provided by the sponsors, and senior bank debt of $251 million[49].

The financing is the first to cover the construction phase which is unusual for offshore wind projects because of the uncertainty. To lower the risks associated with construction a contingent $39 million loan facility was crafted to cover delays or unforeseen expenses, and special availability guarantees in the contract with the operator, Vestas, allow debt repayment to continue during periods when generation is lower than expected[73].

5.4.2 Belwind Bligh Bank Phase One

Belwind NV's project at Bligh Bank in Belgian waters is the largest offshore wind farm financed on a non-recourse basis and was the first such project financed since current global financial troubles began. The financing structure builds upon the experience with the Princess Amalia project. In fact, it has several of the same investors, but also includes funding from the EIB. The EIB is owned by the twenty-seven EU states and finances projects in support of EU strategies and policies. Since the EU supports the development of renewable energy projects so does the EIB and the bank has chosen to emphasize offshore wind[14].

The agreements for this project contain a long-term contract with Electrabel and the grid operator for purchase of the electricity and emissions credits as well as contracts for construction, operation, and maintenance[14]. These agreements together with a contingent facility for cost overages, and repayment guarantees from the operator have made project financing possible.

The $822 million is financed by senior bank debt arranged by ASN Bank, Dexia Group, and Rabobank International with $402 million from the EIB. Subordinated mezzanine financing comes from Rabobank International and Participatie Maatschappi Vlaanderen (PMV) and loan guarantees of over $268 million come from EFK[14].

5.5 Summary

Offshore wind power generation projects are expensive and are sensitive to the cost of capital. High capital costs stem from the nature of the work environment and the requirement that the projects be large in order to achieve a suitable economy of scale. Technology and methods are changing rapidly in this young industry and variations in water depth, design specifications and distance from shore make it difficult to apply costs across projects.

The industry has moved from single party project funding to commercial lending because of uncertainty. Project financing is now achieved through multiple contract funding structures that seek to minimize risk and limit individual exposure by spreading the remaining risk between multiple parties. Financing of offshore wind power projects requires tailor-made solutions and unique contracting structures developed for the specifications of individual projects.

Chapter Six: Cost Model, Cash Flow, and Probabilistic Analysis

The previous chapters summarize many of the challenges facing the offshore wind industry in the United States and everything discussed to this point impacts the costs associated with offshore wind power development. However, one of the largest challenges is concern about the economic viability of projects and uncertainty that the industry will be able to achieve a suitable economy of scale. Offshore projects are expensive and the capital costs required to develop an offshore wind power generation project act as a significant barrier to entry into the industry.

These projects require more costly surveys and pre-project assessments, have higher installations costs, and require higher maintenance and operation expenses than onshore projects of similar capacity. To be economical, offshore wind projects must be large-scale, which necessitates considerable capital expenditure[80], and because of the nature of these projects capital costs represent a larger percentage of total project costs than is typical of traditional electricity plants.

This research project models basic projects costs and uses them provide an estimate of the total net present value for hypothetical utility-scale offshore wind projects in the United States. To achieve this a basic capital cost model was developed and then used to estimate total project costs. The cost model then was used as a basis to set up a cash flow analysis. After completion of the cost model and cash flow spreadsheet a hypothetical average American project was designed and its parameters were used to determine the applicable cash flows and net present value.

Once the values for the hypothetical project were established, response surface methodology and regression techniques were used to determine linear equations for net present value based on certain relevant factors of the hypothetical project.

These equations were used to run a Monte Carlo simulations and generate probabilistic estimates of project viability. Explanation of the modeling approaches, methods, assumptions, and data sources are discussed below.

6.1 Model Cases

Three cases were run through the model. The basic conditions for all three are as follows:

- A water depth of 100ft (30m) which was chosen because the capital cost model is based on a monopile foundation and that type of foundation is suitable between 32 and 130ft[33].
- A distance to shore of 9nm which was chosen because in Texas the state's jurisdiction extends to 9nm and the 8 existing offshore wind leases are located between 8 and 9 nm offshore[85].
- Vessel daily rates of $135,000/day and $15,000/day for installation and support vessels, respectively. These numbers were provided by offshore drilling industry contacts[68].
- A steel price of $800/Long Ton for steel plates. This value corresponds to the March 2008 value used in the source study, but was consistent with current prices[41].
- A piling penetration depth of 65.5 ft. This value was the penetration depth for foundations installed at the Thanet project in the UK[79], which is the project for which the source study obtained domestic fabrication quotes.
- A capacity factor of 35%, which was varied between 28% and 42% during analysis.
- A ten-minute average hub-height mean wind speed of 9m/s. This value was selected after examining NREL estimates of wind strength at 90 m altitude[78]. This value was varied between 6 and 12 m/s during analysis.

- Data from the Energy Information Agency (EIA) was averaged to determine the base electricity price which was 12¢/kWh[31]. This value was varied between 4 and 20 ¢/kWh during analysis.
- A royalty rate of 6.5% was chosen as an average from existing offshore leases.
- The nominal growth rate in electricity price was set as 1% annually.
- The Opex growth rate was set at 2% annually.
- An average corporate tax rate of 35% was used as a basis for figuring tax liability.
- The discount rate is fixed at 10%.
- The Capex, Opex, and Decommissioning costs were imported into the cash flow from the capital cost portion of the model.

The three model cases were chosen to capture small, medium, and large size classes, but the combinations are not exhaustive. The project capacity values were chosen to represent a typical value range between large-scale projects being constructed in Europe and projects that have obtained leases in the United States. Turbine sizes are consistent with those sold currently on the market for large scale offshore wind turbines and range in capacity (size) from 3 to 5 MW each. The rotor diameter values correspond to the actual turbine rotor diameters for offshore turbines on the market and were obtained from manufacturer specifications.

- Medium Capacity/ Medium Turbine Size (MED/MED)
    - 500 MW project capacity.
    - 3.6 MW turbines
    - 357.5 ft (109 m) rotor diameter
- Lower Capacity / Small Turbine Size (LOW/SML)
    - 300 MW project capacity
    - 3 MW turbines

- 295.2 ft (90 m) rotor diameter

- Higher Capacity / Large Turbine Size (HIGH/LGE)
  - 700 MW project capacity
  - 5 MW turbine size
  - 410 ft (125m) rotor diameter

6.2 The Model

6.2.1 Capital Cost Model

The basic approach taken to build this cost model was to research existing publicly available studies that provided specific data and methods used to estimate costs for the major components necessary to develop offshore wind projects in the United States. The source reports used either adapt costs from European experience and/or obtained quotes for domestic component manufacturing and installation. During my research for this project I found four state-level offshore wind feasibility studies - from Virginia[41], North Carolina[86], Wisconsin[71], and Ohio[29] – that contained relevant information. While each of these studies focused on different areas of offshore development, they each included some economic analysis. I adapted the approaches taken in these studies and work done by the National Renewable Energy Laboratory (NREL)[40] on grid connection to create the turbine, foundation, grid connection, and installation portions of the model.

The four model sections listed above represent the bulk of the capital costs, but other substantial costs exist. To estimate lease costs I used a lease issued by the Texas General Land Office (GLO)[84] and press releases from the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE)[18] which stated costs of existing leases.

There was some difficulty determining costs for surveying, engineering, permitting, project management and insurance because I could not find specific information regarding these costs. In order to obtain insight into the issues that affect these costs and discover large costs that were not included in the model initially, I met with a domestic offshore wind farm developer who was able to help identify large costs which were missing from the model and estimate the proportions used on the 'Surveying, Engineering, Planning and Permitting (SEP&P)' tab.

Last, overall project costs ratios published by the NREL[62] were used to estimate total project costs based upon the calculated capital costs.

Basic Assumptions

- The first and most basic assumption made in this model is that project costs can be applied across projects.
- The information provided by the feasibility studies and NREL reports incorporate specific commodity prices, particularly for steel and copper, which can vary substantially. The Virginia report provided enough information so that the price of steel could be incorporated into the model to determine a more accurate foundation cost, however the NREL grid connection report did not provide enough information to allow for a separate model input for copper prices. As a result, this model assumes that the cost of copper and therefore electrical components manufactured using it to be frozen.
- The model does not account for differences in bottom conditions or geotechnical/foundation requirements. As a result is assumes constant, ideal bottom conditions.
- The capital cost model assumes that capital cost is a function of nine factors: water depth at the project location, penetration depth for foundation pilings,

distance to shore that transmission lines must traverse, overall rated project capacity, capacity of individual turbines used, diameter of the turbine's rotor, price of steel per long ton, and the daily rental rates for installation and supply vessels

- The model assumes that a monopile foundation will be used.

Tab-by-Tab Assumptions and Explanation

- Turbines
  - The turbine calculation assumes that all components above the transition piece are included in the price.
  - This tab uses two estimates of turbine cost from the Ohio study, two from the Virginia study, and the average value as data points. These five points were plotted in Excel using the trend line function which determined the best fit and corresponding equation. This polynomial equations is

$$TC = 44146.31TS^2 - 121756.72TS + 1923610$$

    where TC = cost per turbine and TS = individual turbine size in megawatts. This equation calculates a cost per megawatt, which then is multiplied by the total project capacity to get to turbine cost.
  - The prices obtained from the Virginia and Ohio feasibility studies that were used are assumed to represent average values.
- Foundations
  - The foundation calculation is based on the Virginia feasibility study which obtained quotes from a local fabricator for the domestic production of the foundations used at the Thanet project in the United Kingdom. Thus this calculation is based monopile foundation for 3MW turbines with an average piling penetration depth of 21m[79]. This tab recreates the Virginia calculation using the same 1.4

multiplier for overhead and 10% profit used in the study[41]. The model assumes that this represents an average value.

- The base steel price and penetration depth are those from the Virginia study and Thanet project, respectively, although they are model inputs which can be varied.
- This tab adapts the Virginia methodology down to a unit foundation cost per foot of depth per MW and then calculates the foundation cost based on this unit cost, number of turbines, turbine size, and depth (water depth plus penetration depth).
- In order to correct for different turbine sizes the model creates a table from the turbine cost data for turbines of various sizes and compares each to a 3MW turbine. The ratios for different sizes of turbines are assumed to be the same as the ratios for different sizes of foundations. These ratios are used to correct foundation cost to those required for turbines of sizes other than 3MW.

- Grid Connection
  - This tab adapts the method presented in the NREL paper, "Electrical Collection and Transmission Systems for Offshore Wind Power[40]" in which the authors figured connection costs based on prices obtained from component manufacturers.
  - It assumes a turbine separation equal to 7 times the rotor diameter (as NREL does) and that the spacing between turbines within the same row and spacing between rows are equal. This assumption allows for acreage required and collection cable length to be calculated as if the turbines were configured all in one long row.
  - It assumes an additional cable requirement of 30% of the required length to account for necessary cable curvature and routing around sea bottom features.

- This tab adopts several assumptions from the NREL source report including: a 630mm^2 cable size for both collection and transmission cables, 1 offshore substation per 180MW of capacity, 1 transmission cable to shore from each offshore substation, and a unit cost per MW which was derived from the onshore substation for a 500MW project[11]. The onshore substation cost is found by multiplying the unit cost by the overall project capacity input.

- Installation
  - The daily rates for vessels used for turbine and foundation installation are numbers provided by oil and gas industry contacts that regularly contract vessels in the Gulf of Mexico[68].
  - This tab assumes that turbine installation will require 1 day per turbine and 2 days per foundation, and that support vessels will be needed for each installation day. These day values were chosen as average values and are intended to include transit time required to pick up additional components.
  - Cable installation costs were based on NREL figures and assumed the average between the east and west coast values stated in their report[40].
- Surveying, Engineering, Planning, and Permitting (SEP&P)
  - The SEP&P tab calculates values for several smaller, but important, project costs.
  - The assumed 'per acre' value for land rent is an average of the two actual lease 'per acre' values available[16,73] and the number of acres is based on data provided by GLO leases[84], BOEMRE press releases[18], and the website of a domestic offshore wind developer[102].
  - Cable surveying and planning costs were obtained from the NREL report[40].

- Other SEP&P costs had to be assumed as percentages of the total capital costs as projected from the sum of the costs of turbines, foundations, grid connection, installation, land rent, and cable surveying and planning costs. Appropriate approximate percentages for project management, turbine and foundation surveying and engineering, permitting and environmental impact assessments, and insurance and marine warranty were obtained through conversation with a domestic offshore wind developer[13].

- Overall Project Costs
  - The estimation of overall project costs are based on relative percentages of capital costs to total costs published in the NREL report "Energy From Offshore Wind[62]", which examined the actual proportions of cost categories for installed offshore wind projects.
  - The assumption used here is that capital costs are predominantly made up of turbines, foundations, grid connection, and their installation.

Cost Model Analysis and Verification - The Virginia study concluded that the capital costs of offshore wind power would be between $3000 and $3600 per kilowatt[41], and the North Carolina study obtained an average cost of $3360 per kilowatt for coastal ocean projects[86]. A calculation was entered on the 'Overall' tab of the model to compare the capital cost results generated with those values from the Virginia and North Carolina studies by obtaining a dollar per kilowatt value for the hypothetical projects. Model values in dollars per kilowatt are shown in Table 6.1 for nine project configurations. One can see that for projects of different total capacities that use the same turbine size lower per kilowatt costs result for larger projects, illustrating better economy of scale for larger projects.

Table 6.1: Project Capital Costs in $/kW

Project Capacity (MW)	Turbine Size (MW)	Rotor Diameter (ft, m)	CAPEX (Mill$)	CAPEX ($/kW)
300 MW (LOW/ SML)	3 MW	295.2, 90	935.1	3117
500 MW	3 MW	295.2, 90	1553.1	3106
700 MW	3 MW	295.2, 90	2171.1	3102
300 MW	3.6 MW	257.5, 109	966.6	3222
500 MW (MED/ MED)	3.6 MW	257.5, 109	1606.8	3211
700 MW	3.6 MW	257.5, 109	2244.5	3206
300 MW	5 MW	410, 125	1083.1	3610
500 MW	5 MW	410, 125	1799.8	3600
700 MW (HIGH/ LGE)	5 MW	410, 125	2516.4	3595

Each of the source studies for the different components of the capital and total cost estimates are based upon specific assumptions. In order to remove the worst effects of the source studies' assumptions different pages of the model incorporate correction factors that adjust the model components so that they can be applicable in general. Upon inclusion of the correction factors described in the tab-by-tab assumptions above, the values for hypothetical projects correspond with those in the North Carolina and Virginia studies.

As mentioned above, the information used to generate prices for the major components are dependent upon commodity prices, particularly those of steel and copper. While it was possible to include the price for steel as a variable in the foundation cost calculation, other portions of the model assume commodity prices to be frozen, and not necessarily frozen at the same price in separate calculations of different component costs. Also, the assumption of an unchanging, ideal bottom type does not reflect the reality for projects, as the sea bottom is not consistent in any location.

Last, it was difficult to determine a calculation for many of the smaller capital cost factors and some of these factors had to be estimated as percentages of total capital cost. This method magnifies any errors that exist in other portions of the model and is limited to an assumption of percentage. It would be better if a separate method for calculating these cost components could be employed.

6.2.2 Cash Flow Analysis

Once capital cost elements could be determined a traditional cash flow analysis was generated to examine the net present value (NPV) for offshore wind projects. The model inputs are wind farm capacity, turbine size, rotor diameter, capacity factor (cf), average mean wind speed (AMWS), electricity price (P), royalty rate, nominal growth rate in electricity price, OPEX present value from capital cost model, growth rate in OPEX, CAPEX from capital cost model, Decommissioning Cost from capital cost model, discount rate, tax rate, production tax credit amount, and investment tax credit percentage. The sole calculated output is NPV.

Basic Assumptions

- The cash flow assumes a project life span of twenty years. This value was chosen because it corresponds to the operational life span of traditional wind turbines. In reality new offshore projects may benefit from technological advancements and are likely to have longer project life times.
- Decision variables such as project capacity, turbine size, and rotor diameter were considered to be fixed once the hypothetical project parameters were selected.
- Rates such as discount rate, corporate tax rate, inflation rate, royalty rate and the growth rates for price and OPEX are available as inputs, but reasonable values were determined for each of these factors and these rates are considered to be fixed.

- Annual production throughout the life of the project is constant.

Model Explanation

In order to calculate NPV the cash flow estimates the amount of electricity that would be generated by the selected project per year by the calculation:

$$\Pr = \frac{0.5\rho AV^3 cf(Ta)(\#T)(31536000)}{3.6x10^6}$$

Where Pr=production in kWh, ρ = air density, A = rotor swept area, V = average mean wind speed, cf = capacity factor, Ta = turbine availability, #T = the number of turbines, 31536000 = seconds/year, and 3.6E6 = the conversion factor from Joules to Kilowatt Hours.

The cash flow then subtracts the royalty portion due to the leasing entity and calculates annual net revenue based on an electricity price that increases by 1% per year. Next, operational expenses (OPEX) and depreciated capital costs (CAPEX) are subtracted to get the taxable income. The inputs for OPEX and CAPEX are generated by the capital cost model. CAPEX represents the total capital costs and is depreciated using straight line depreciation with a seven year term and no salvage value as shown in the following equation:

$$Dt = \frac{Co - 0}{7}$$

Where Dt = annual depreciation allowance, and Co = CAPEX. The OPEX costs are calculated by adding the “Operations & Maintenance” and “Management” values from the total project costs portion of the capital cost model. This OPEX value is the present value for total project OPEX and had to be apportioned annually for the cash flow. The following annuity equation was used to determine the initial installment for cash flow OPEX:

$$O_1 = \frac{CCO}{\left[1 - \frac{(1+g)^{20}}{(1+r)^{20}}\right]}(r-g)$$

where O_1 = POEX in year 1, CCO = OPEX costs from the capital cost model, g = OPEX growth rate, r = discount rate, and 20 = years of project life.

After calculation of taxes due, using an average corporate tax rate of thirty-five percent, the annual after tax cash flows to equity are calculated as follows:

$$ATCF = ATI + Dt - CAPEX - DC + PTC + ITC$$

Where ATCF = after tax cash flow, ATI = after tax income, Dt = annual depreciation allowance, DC = decommissioning cost, PTC = production tax credit, and ITC = investment tax credit. The decommissioning cost for year 20 is calculated using the present value of decommissioning cost from the capital cost model and the future value function in Excel with a 10% discount rate and 20-year period.

Last, to obtain project NPV, the annual ATCF's are discounted by the equation:

$$DATCF = \frac{ATCF}{(1+r)^t}$$

where DATCF = discounted after tax cash flow, ATCF = after tax cash flow, r = discount rate, and t = time in years. The DATCF's are summed to get project NPV:

$$NPV = \sum DATCF$$

6.2.3 Design of Experiments

In order to generate probabilistic estimates of project NPV, equations for NPV had to be generated. Once the cash flow spreadsheet was complete the sensitivity of output (NPV) to the various cash flow inputs was estimated using the data sensitivity functions in Excel. Figure 6.1 shows a tornado diagram of the relevant factors.

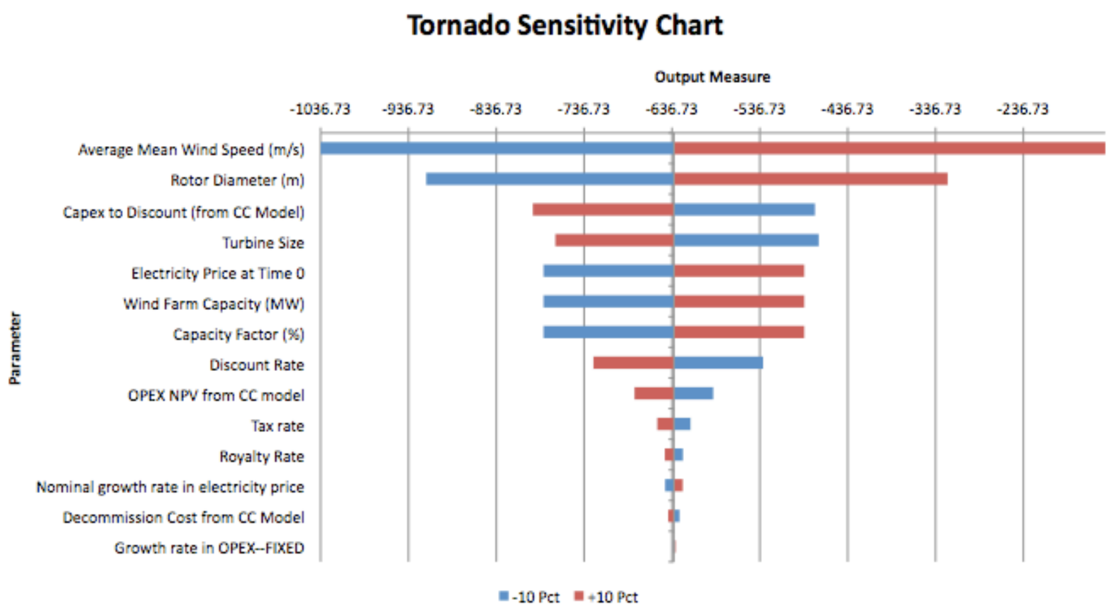


Figure 6.1: Tornado Sensitivity Chart of Cash Flow to Inputs

The sensitivity analysis was conducted for all of the cash flow inputs by estimating the range in NPV that would result from varying each input by +/_ 10%. Results that varied less than 50 million dollars were considered insignificant. Nine factors exceeded this threshold as shown in Table 6.2 below.

Table 6.2: Resultant NPV Fluctuation for Significant Factors in Mill$

Average	Rotor	CAPEX	Turbine	Price	Wind	Capacity	OPEX	Disc.

Mean Wind Speed	Diameter		Size	per kWh	Farm Capacity	Factor		Rate
893.3	593.6	321.2	299.8	296.8	296.8	296.8	193.1	89.6

To simplify the analysis, decision variables – rotor diameter, turbine size, and wind farm capacity – were considered to be fixed at the values used in the CAPEX model, and discount rate was fixed at 10%. The remaining five variables are all considered to be uncertainties.

To estimate the effect of each uncertainty on overall project NPV response surface methodology (RSM) was employed. RSM allows for exploration of the relationships between variables and the overall outputs by examining key points on the three-dimensional geometric shape that corresponds to the number of changing variables[63].

For this analysis the Box Behnken Design (BBD) RSM was used to determine which combination of the selected variables needed to be analyzed to evaluate the response in NPV. The BBD method allows one to systematically look at the center points along the edges of the geometric surface[61]. For a five factor (variable) experiment each factor is assigned three levels – good (+1), base (0), and bad (-1) – and two factors are varied per trial. If every combination of these 5 variables were to be examined 3^5 or 243 data runs would be required per experiment. The BBD method provides a means to determine a characteristic response in 41 data runs – 1 run in which all values are considered at the base (0) value, and 40 runs where two of the variables are considered at their (+1) or (-1) values[63]. The matrix of experimental runs for a 5 factor BBD is shown in Figure 6.2.

x1	x2	x3	x4	x5
+/- 1	+/- 1	0	0	0
+/- 1	0	+/- 1	0	0
+/- 1	0	0	+/- 1	0
+/- 1	0	0	0	+/- 1
0	+/- 1	+/- 1	0	0
0	+/- 1	0	+/- 1	0
0	+/- 1	0	0	+/- 1
0	0	+/- 1	+/- 1	0
0	0	+/- 1	0	+/- 1
0	0	0	+/- 1	+/- 1
0	0	0	0	0

Figure 6.2: Five Factor BBD Design of Experiments[63]

Each of these 41 data combinations was run through the cash flow model and 41 corresponding NPV's were determined. The combination of variables run during each trail and the resulting NPV's were recorded and linear regression was used to find the equation that best fit the recorded data. Initially, other regressions were done in order to determine whether the characteristic equation would be linear or second order, but the x-squared and cross product terms were insignificant, so the simpler linear regression was used.

6.2.4 Monte Carlo Simulation

Once the characteristic equations were determined, random sampling techniques were used to determine a probabilistic estimate of project value. For each of the five uncertainties 1000 random number samples were generated using uniform distribution between max and min values that were within the ranges used during the design of experiments. From each of these 1000 sets of uncertain sample data a distribution of NPV was calculated using the linear equations found via regression as described above.

From this data mean NPV, P90 values, P10 values, and the percentage of negative NPV results were calculated. The number below which 90% of the data returns lay is the P90 value. The number below which 10% of the data returns lay is P10. For each case a histogram showing the NPV distribution and cumulative density function was generated.

6.3 Results

The three levels of each variable, NPV equation generated, and sample NPV distribution for each of the model cases are displayed below.

6.3.1 The MED/MED case:

In this case the equation generated by linear regression fit 92.2% of the sample data.

Table 6.3: Variable Ranges for the MED/MED Case

MED/ MED	Capacity Factor (%)	AMWS (m/s)	Electricity Price ($/kWh)	OPEX (Mill$)	CAPEX (Mill$)	Calculated NPV (Mill$)
-1	0.28	6	0.04	618	1900	-2443
0	0.35	9	0.12	537	1606	-635
+1	0.42	12	0.2	456	1400	4009

$$NPV = -5621.329 + 4173.214cf + 459AMWS + 12435.938P - 0.81096Op - 0.96519Cap$$

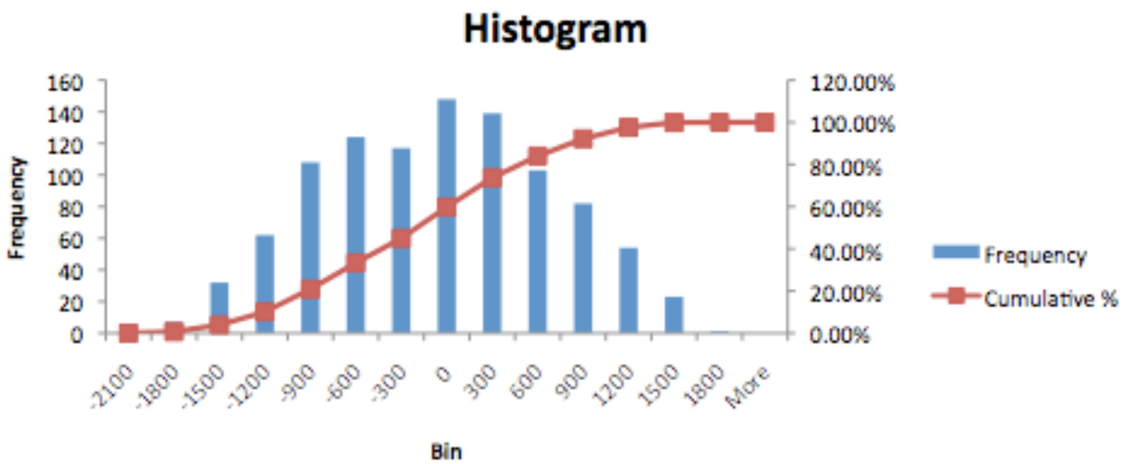


Figure 6.3: NPV Distribution Resulting from the MED/MED Case

6.3.2 The LOW/SML case:

In this case the equation generated by linear regression fit 92.3% of the sample data.

Table 6.4: Variable Ranges for the LOW/SML Case

LOW/ SML	Capacity Factor (%)	AMWS (m/s)	Electricity Price ($/kWh)	OPEX (Mill$)	CAPEX (Mill$)	Calculated NPV (Mill$)
-1	0.28	6	0.04	359	1140	-1468
0	0.35	9	0.12	312	935	-504
+1	0.42	12	0.2	265	840	840

$$NPV = -2817.942 + 2100cf + 233.146AMWS + 6296.875P - 0.84973Op - 1.0105Cap$$

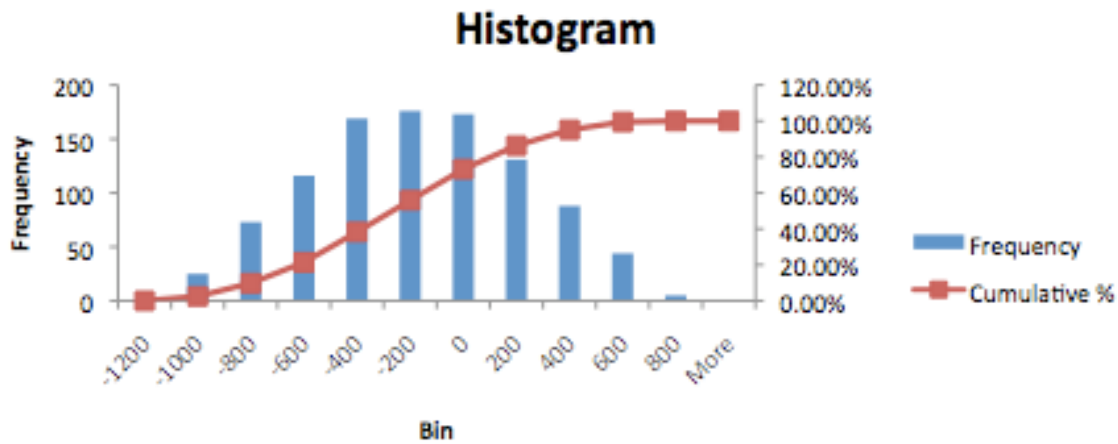


Figure 6.4: NPV Distribution Resulting from the LOW/SML Case

6.3.3 The HIGH/LGE Case:

In this case the equation generated by linear regression fit 92.0% of the sample data.

Table 6.5: Variable Ranges for the HIGH/LGE Case

HIGH/ LGE	Capacity Factor (%)	AMWS (m/s)	Electricity Price ($/kWh)	OPEX (Mill$)	CAPEX (Mill$)	Calculated NPV (Mill$)
-1	0.28	6	0.04	968	2660	-3545
0	0.35	9	0.12	842	2516	-1353
+1	0.42	12	0.2	716	1960	5147

$$NPV = -8000.999 + 5613.393cf + 625.729AMWS + 16943.75P - 1.3194Op - 1.2469Cap$$

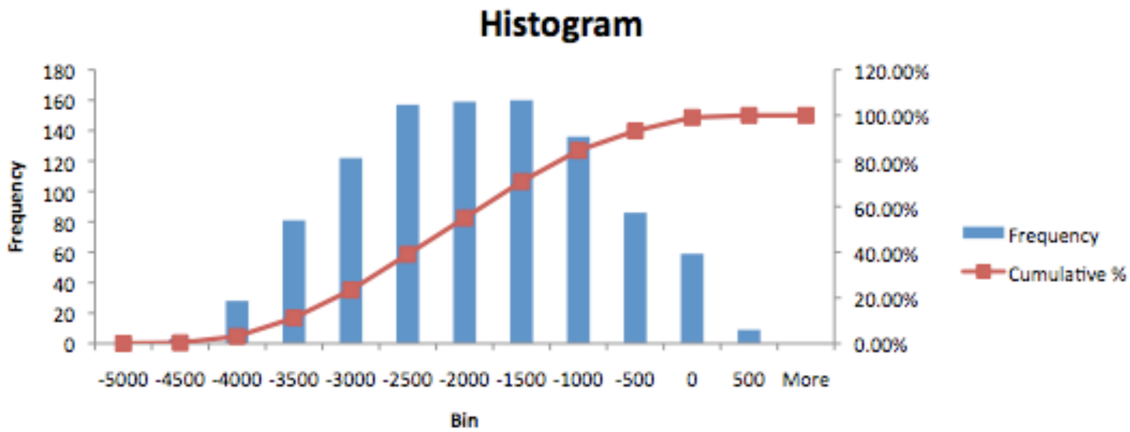


Figure 6.5: NPV Distribution Resulting from the HIGH/LGE Case

For all three cases the statistical values are shown in Table 6.6, below. The last column of the table shows the percentage of negative NPV's that resulted from the random samples. All non-percentile values are in millions of dollars.

Table 6.6: Model Case Statistical Values

Case	**Mean**	**P90**	**P50**	**P10**	**% Negative**
MED/MED	-211.8	753.0	-211.8	-1176.6	61%
LOW/SML	-261.8	245.1	-261.8	-768.8	75%
HIGH/LGE	-2148.8	-800.3	-2148.8	-3497.2	98%

6.3.4 Break Even Points

As can be seen in the data shown above, for all three base cases the majority of resultant NPV's were negative. For further evaluation of these experiments the electricity price and wind speed necessary to make the projects break even, or give a NPV of zero were calculated using the cash flow model. However, break-even points do not represent values that remove project risk because other variables still are uncertain. In order to estimate values of electricity price and wind speed that would reduce risk and motivate investment, values of price and wind speed were determined that make the P90 NPV equal to zero (that is, the levels that make 90%

of the NPV's positive). Table 6.8 shows both the break even and low risk values for all three experimental cases.

According to the Energy Information Agency (EIA) current residential electricity prices range from 7.28 – 16.98 cents/kWh[31]. The National Renewable Energy Laboratory (NREL) estimates that 16.8% of US offshore areas have average mean wind speeds between 9 – 10 m/s at 90 m altitude and only 2.1% have average mean wind speeds higher than 10 m/s[78]. As one can see from Table 6.8 for all of the basic experiments the necessary prices and wind speeds exceed the highest reasonable values.

6.3.5 Real World Cases

Similar to the base case experiments break even and low risk points were calculated for three real-world cases. Each of these cases closely copies an installed project or a well-developed planned project. The Massachusetts Hypothetical case is modeled after the Cape Wind & Associates project in Massachusetts, which is the first project to complete leasing and permitting processes in the United States. The specifications of this case are similar to the MED/MED base case. The Thanet Hypothetical project is modeled after the Thanet project in the United Kingdom. It was chosen because its foundations were used as the basis in the source study upon which the 'foundations' portion of the capital cost model is figured. The Thanet project is similar to the LOW/SML case. The Texas Hypothetical project is modeled after Baryonyx Corporation's large-scale planned projects that have leases in Texas. The Texas project is similar to the HIGH/LGE case. Individual project parameters are a combination of actual project data and reasonable measurements which were used to fill gaps where actual project data was not publically available.

Table 6.7: Real World Project Parameters

Project Name	Similar Class	Water Depth (ft, m)	Distance to Shore (nm)	Total Capacity (MW)	Turbine Size (MW)	Rotor Diameter (ft, m)
Massachusetts Hypothetical	MED/ MED	65.6, 20	10.4	468	3.6	377.2, 115
Thanet Hypothetical	LOW/ SML	73.8, 22.5	6.5	300	3	295.2, 90
Texas Hypothetical	HIGH/ LGE	131.2, 40	8	700	5	410, 125

The break even and low risk values for the real world cases also are shown in Table 6.8. As one can see from the table, some of the real world cases have values that are feasible, even though the experiment cases did not. For the low risk values of the hypothetical projects the P90 values from the similar class was used.

Table 6.8: Experimental and Real-World Break Even and Low Risk Points

Project/Case	BE Price ($/kWh)	BE AMWS (m/s)	LR Price ($/kWh)	LR AMWS (m/s)
MED/MED	0.1714	10.135	0.2495	11.488
LOW/SML	0.2032	10.726	0.2546	11.565
HIGH/LRG	0.2025	10.716	n/a	n/a
Massachusetts Hypothetical	0.1494	9.683	0.2246	11.091
Thanet Hypothetical	0.1951	10.583	0.2466	11.442
Texas Hypothetical	0.2092	10.832	n/a	n/a

The table shows break-even points of approximately 15 ¢ and 9.7 m/s for the Massachusetts Hypothetical project. These values fall within the ranges of current electricity prices and reasonable wind speeds discussed above. Since these values were the most reasonable of the real world projects, the Massachusetts Hypothetical was run through the entire model to generate a probabilistic estimate of project

NPV, using the MED/MED equation. In this analysis the electricity price was fixed at 0.18 $/kWh, which removed the price uncertainty. This adjustment was made because the Cape Wind project upon which the Massachusetts Hypothetical project is based has a contract to sell its generated electricity at this price[21]. The samples of the other four variables were randomly generated along a uniform distribution, in the same manner as the base case experiments.

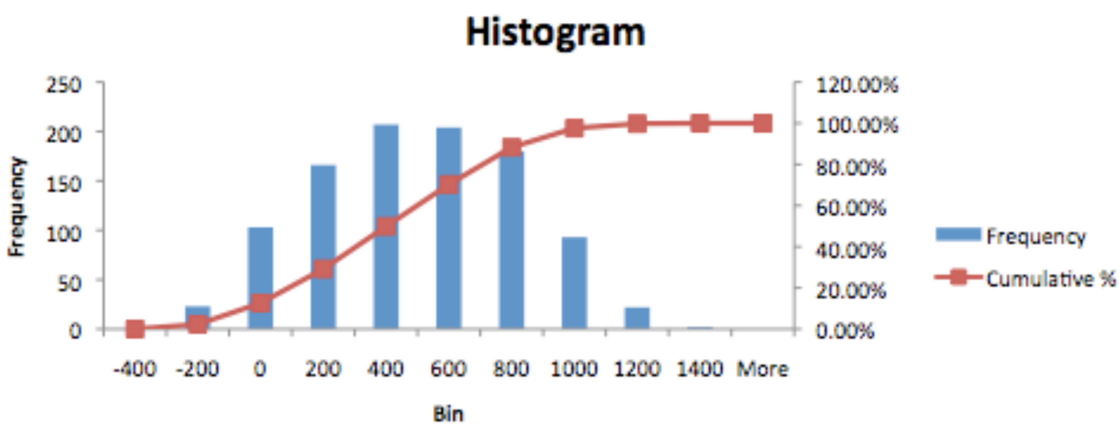


Figure 6.6: NPV Distribution Resulting from the Massachusetts Hypothetical Project

The results for the Massachusetts Hypothetical project are shown in Figure 6.6. The mean was $397 million, the P90 value was $812 million and only 11% of the sample NPV's were negative. The model shows this project to be economically viable.

6.4 Production Tax Credits

As can be seen from the results, in general at this time, offshore wind projects in the United States are marginally profitable, with specific exceptions. As was discussed in previous chapters, the federal government offers production and investment tax credits that are designed to help the financial viability of renewable projects. The current production tax credit (PTC) is 0.021 $/kWh of electricity generated and the current investment tax credit (ITC) is 30% of the initial investment[9].

The cost analysis to this point did not include any tax credits because neither the current PTC nor ITC are long-term incentives. PTC's help lower the costs of projects by lowering the tax burden. If the current level of PTC became long-term then the break even and low risk points shown in Table 6.9 result for the model base cases and real world cases.

Table 6.9: Break Even and Low Risk Electricity Price and Wind Speed with PTC

Project/Case	**10 BE Price**	**10 BE WSpd**	**10 LR Price**	**10 LR WSpd**	**20 BE Price**	**20 BE WSpd**	**20 LR Price**	**20 LR WSpd**
MED/MED	0.1535	9.677	0.2265	10.833	0.1466	9.52	0.2175	10.617
LOW/SML	0.1835	10.241	0.2315	10.906	0.1783	10.076	0.2226	10.704
HIGH/LRG	0.1847	10.231	n/a	n/a	0.1778	10.067	n/a	n/a
Massachusetts Hypothetical	0.1316	9.245	0.2074	10.550	0.1247	9.096	0.1985	10.340
Thanet Hypothetical	0.1703	9.942	0.2146	10.586	0.1772	10.104	0.2235	10.790
Texas Hypothetical	0.1913	10.342	n/a	n/a	0.1844	10.176	n/a	n/a

The first four columns describe a 10-year PTC; the last four columns describe a 20-year PTC. These numbers were calculated using the cash flow model and assuming that there are no other restrictions on being able to claim the credit than the amount of electricity produced. The low risk values for the Massachusetts Hypothetical project used the P90 values generated above for that case; for the Thanet Hypothetical project the P90 value for the LOW/SML case was used. The P90 value for the HIGH/LGE case was negative so no low risk values exist for the HIGH/LGE or Texas Hypothetical projects.

6.5 Summary

Public cost analyses for total capital costs and overall projects costs have not been available to date. This chapter introduces these cost models and employs traditional cash flow analysis, design of experiments and random sampling techniques to generate equations for NPV and probabilistic estimates for project value for American offshore wind projects. This model illustrates that such analysis techniques can be applied to this type of project.

Even though the base case experiments used to derive equations for NPV of offshore wind projects were generated from project sets that had predominantly negative NPV's the equations are valid for projects whose parameters fall within the experimental design value ranges that may be economically viable. As can be seen from the data results shown, the base case US projects are marginally profitable, however, individual, specific projects can have favorable project economics.

Chapter Seven: Conclusions

- Numerous challenges face the offshore wind industry that must be addressed in order for a strong industry to develop in the United States. These issues must be addressed to enhance predictability and reduce uncertainty in this developing industry.

- Traditional cash flow analysis, design of experiments and random sampling techniques can be applied to offshore wind projects to generate characteristic equations and probabilistic estimates of project value.

- Without a long-term tax credit the base case US projects are marginally profitable, however, individual, specific projects can have favorable project economics

- While the model cases had predominantly negative results the equations derived to calculated project NPV are valid for projects whose parameters fall within the experimental design value ranges which may be economically viable.

- Project financing is now achieved through multiple contract funding structures that seek to minimize risk and limit individual exposure by spreading the remaining risk between multiple parties. Financing of offshore wind power projects requires tailor-made solutions and unique contracting structures developed for the specifications of individual projects.

- A greater economy of scale is achieved in larger capacity projects than in smaller capacity ones using the same turbine size.

- The development of offshore wind projects has potential impacts, which, in many cases, can be minimized or mitigated. Issues exist where evidence is sparse and additional study is required. Areas where determinations of risk are uncertain require further study including the completion of studies prior to construction and comparison with post-installation assessments for early projects.

- Consideration of factors that increase potential impacts is prudent to choosing a proper project location and will minimize conflicting uses and aid in project approval.

- The developing US offshore wind industry would benefit from passage of a national renewable portfolio standard, legislation that places values on externalities, and long-term financial commitments. Legislation approving any or all of these would help reduce uncertainty and aid proper planning for offshore wind projects.

- Intergovernmental coordination is a key ingredient smooth growth of an American offshore wind industry. Collaborative efforts will help resolve issues originating from jurisdictional overlap and lead to organized leasing and permitting processes.

- The American offshore wind industry faces several technical needs and challenges. The industry will benefit from additional research and developments that increase reliability, quantification of design loads, survivability of extreme environmental events, and better forecasting methods.

- Solutions to technical challenges and development of domestic infrastructure will help achieve needed cost reductions for American projects. Numerous entities are working to address these key issues and help ensure that a technologically sound industry emerges.

Appendix One: Global Installed Offshore Wind Projects, (End of 2010)

Name	**Location (by Country)**	**Capacity (MW)**	**Number of Turbines**	**Date Completed**
Vindeby	Denmark	5	11	1991
Lely	Netherlands	2	4	1994
Tuno Knob	Denmark	5	10	1995
Irene Vorrink (Dronten)	Netherlands	17	28	1996
Gotland (Bockstigen)	Sweden	3	5	1998
Blyth Offshore	United Kingdom	4	2	2000
Middlegrunden	Denmark	40	20	2001
Utgrunden	Sweden	11	7	2001
Yttre Stengrund	Sweden	10	5	2001
Horns Rev	Denmark	160	80	2002
Frederikshavn phase 1	Denmark	3	1	2002
Frederikshavn phase 2	Denmark	8	3	2003
Nysted Havmollepark	Denmark	166	72	2003
Ronland	Denmark	17	8	2003
Samso	Denmark	23	10	2003
North Hoyle	United Kingdom	60	30	2004
Arklow Bank phase 1	Ireland	25	7	2004
Ems Emden (Enova)	Germany	5	1	2004
Hokkaido	Japan	1	2	2004
Scroby Sands	United Kingdom	60	30	2004
Kentish Flats	United Kingdom	90	30	2005
Barrow Offshore Wind	United Kingdom	90	30	2006
Breitling	Germany	3	1	2006
Egmond aan Zee	Netherlands	108	36	2006
Beatrice Demonstration	United Kingdom	10	2	2007
Burbo Offshore	United Kingdom	90	25	2007

Wind Farm				
Kemi Ajos phase I	Finland	9	3	2007
Lillgrund	Sweden	110	48	2007
Suizhong 36-1	China	2	1	2007
Inner Dowsing	United Kingdom	97	27	2008
Kemi Ajos phase II	Finland	15	5	2008
Princess Amalia (Q7)	Netherlands	120	60	2008
Lynn	United Kingdom	97	27	2008
Hooksiel Demonstrator	Germany	5	1	2008
Thornton Bank	Belgium	30	6	2008
Hywind (Test Project)	Norway	2.3	1	2009
Gasslingegrund	Sweden	30	10	2009
Rhyl Flats	United Kingdom	90	25	2009
Horns Rev 2	Denmark	209.3	91	2009
Alpha Ventus	Germany	60	12	2010
Pori Offshore 1	Finland	24	8	2010
Poseidon Wind & Wave	Denmark	0.033	3	2010
Nysted II (Rodsand II)	Denmark	207	90	2010
Shanghai Donghai Bridge	China	102	34	2010
Robin Rigg	United Kingdom	180	60	2010
Gunfleet Sands	United Kingdom	172.8	48	2010
Thanet	United Kingdom	300	100	2010
Totals	**47 Projects**	**2878.4 MW**	**1120 Turbines**	**----**

Source: Data complied from Koppits and Westwood[50], the European Offshore Wind Energy Association[34], and the New York Times[107].

Appendix Two: State-by-State Data (Alphabetical by State)

State	Coastal Region	Renewable Portfolio Standards	State Incentives Applicable to Offshore Wind*	Other Declared Interest**
Alabama	Gulf of Mexico	N/A	N/A	N
Alaska	North Pacific	50% by 2025***	Loan and Grant Programs	N
California	Pacific	20% by 2010	N/A	N
Connecticut	Atlantic	23% by 2020	N/A	N
Delaware	Atlantic	25% by 2025	Grant Program	Y
Florida	Atlantic; Gulf of Mexico	N/A	N/A	
Georgia	Atlantic	N/A	N/A	N
Hawaii	Pacific Islands	40% by 2030	Corporate Tax Credit; Feed-in Tariff	
Illinois	Great Lakes	25% by 2025	Bond and Loan Programs	N
Indiana	Great Lakes	N/A	N/A	N
Louisiana	Gulf of Mexico	N/A	N/A	N
Maine	Atlantic	40% by 2017	Performance Based Incentive	Y
Maryland	Atlantic	20% by 2020	Corporate Tax Credit (PTC)	Y
Massachusetts	Atlantic	11.1% by 2009 + 1% per year	Loan Program	Y
Michigan	Great Lakes	10% by 2015	Corporate Tax Credits; Grant Program	Y
Minnesota	Great Lakes	25% by 2050	N/A	N
Mississippi	Gulf of Mexico	N/A	N/A	N
New Hampshire	Atlantic	23.8% by 2025	N/A	Y
New Jersey	Atlantic	22.5% by 2021	N/A	Y
New York	Atlantic;	30% by 2015	N/A	Y

	Great Lakes			
North Carolina	Atlantic	12.5% by 2010 or 10% by 2018****	Corporate Tax Credit	Y
Ohio	Great Lakes	12.5% by 2024	N/A	Y
Oregon	Pacific	5-10% or 25% by 2025****	Loan Program; Corporate Tax Credit	
Pennsylvania	Great Lakes	8.5% by 2020	Loan and Grant Programs; Loan Guarantees	N
Rhode Island	Atlantic	16% by 2019	N/A	Y
South Carolina	Atlantic	N/A	N/A	
Texas	Gulf of Mexico	5,880MW by 2015	Corporate Tax Deduction or Exemption	Y
Virginia	Atlantic	15% by 2025**	N/A	Y
Washington	Pacific	15% by 2020	N/A	N
Wisconsin	Great Lakes	10% by 2015	Grant and Loan Programs	Y

Sources: This data was compiled from the following sources: RPS data produced by Lawrence Berkeley National Laboratory[106]; Wind resource data from the National Renewable Energy Laboratory[78]; and state incentives information from the DSIRE database[30].

*Data are not included for information on incentives associated with sales tax and use because the locations of many necessary supply chain assets are not known yet. Similarly, exclusions from property tax valuations are not included because the projects will be located on public lands. Also, there are some performance-based incentives offered by individual utilities for systems up to 10 and 20 MW, but these are not included because they are utility specific and are not offered by the states.

**Other Declared Interest can include an established leasing program for offshore wind, establishment of an offshore wind (inter-governmental) task-force or collaborative, specific carve-out of the RPS for offshore wind, etc.

***The state renewable portfolio standard in non-binding.

****The RPS's in these states are tiered based on utility category. North Carolina has two tiers: 12.5% by 2010 for investor-owned utilities and 10% by 2018 for cooperatives and municipally-owned utilities. Oregon's RPS requires 25% from large utilities and 5-10% from small utilities.

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